FACILITATING ANALOGICAL TRANSFER
IN A HYPOTHETICO-DEDUCTIVE REASONING TASK:
THE CONTRIBUTIONS OF SURFACE AND STRUCTURAL SIMILARITY

By

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The Blackboard and Pythagoras versions of the THOG problem were utilized to investigate how surface and structural similarity contribute to analogical transfer in this hypothetico-deductive reasoning task. In experimental groups of 12 or fewer, 466 University of Florida introductory psychology students separately solved source and target problems, and then described any problem similarities and their facilitating effects. In Experiment 1, significant transfer was observed for both THOG problems when surface similarity between source and target problems was maintained. In Experiment 2, changing the dimensional values of the geometric figures in the target problem decreased surface similarity. The Pythagoras produced analogical transfer whereas the Blackboard did not and was dropped from further experimental investigation. In Experiment 3, the target problem's geometric designs were replaced with the dimensions of letters and numbers, and the Pythagoras again yielded transfer. In Experiment 4, three versions of the Pythagoras problem were created, and a hypothesis generation request in combination with either figural labeling or narrative structure produced analogical transfer.

These experiments revealed that participants could solve the difficult abstract THOG task, in the absence of surface similarity, if they abstracted its solution principle from a source problem. When surface similarity was reduced, it was necessary for the source problem to entail features that separated the values of the exemplar from the possible written down combinations and requested participants to generate hypotheses for these combinations. These findings contribute to our understanding of both hypothetico-deductive reasoning and analogical transfer. First, confusion theory was supported by the finding that separation and reduced working memory load yielded both facilitation and transfer. Second, indirect experimental help (i.e., a hypothesis generation request) was necessary to obtain transfer. Finally, the primacy of structural similarity to analogical transfer was interpreted as supporting pragmatic schema theory and structure mapping theory. These results suggest the majority of adults can reason hypothetically and deductively on the THOG task if they are led to abstract its underlying solution principle.

CHAPTER 1
INTRODUCTION

The doctrine of "formal discipline," dating back to the teachings of Plato and presented in its classic form by John Locke (Dewey, 1916), in many respects lies at the heart of spontaneous analogical transfer. According to formal discipline, the mind is like a "muscle" that must be trained in certain faculties, such as observation, attention, and reasoning, in order to strengthen these processes (Singley & Anderson, 1989). Locke believed the content studied in order to "exercise" these faculties was somewhat irrelevant. Rather, he proposed it was the amount of exertion required to master a given ability that was most important (Dewey, 1916). The primary purpose of formal education then, as proposed by formal discipline, should be to focus on those content areas likely to train specific cognitive processes that can then be applied (transferred) across many disciplines.

The first to empirically test the tenets of formal discipline was E. L. Thorndike (1906, 1913). In a research endeavor spanning over a quarter century using a variety of tasks, Thorndike determined that the type of spontaneous transfer proposed to result from formal discipline training was entirely too wide in scope. He suggested that rather than entailing particular faculties, the mind is composed of specific associations and habits that narrow dramatically the types of responses that can be expected in any given situation. As a consequence, transfer between activities should only be expected if there is a high degree of similarity (i.e., shared common stimulus-response elements).

Thorndike's theory of transfer, called the theory of identical elements, proposed that:

> One mental function or activity improves others insofar as and because they are in part identical with it, because it contains elements common to them. Addition improves multiplication because multiplication is largely addition; knowledge of Latin gives increased ability to learn French because many of the facts learned in the one case are needed in the other . . . [T]he mind is so specialized into a multitude of independent capacities that we alter human nature only in small spots, and any special school training has a much narrower influence upon the mind as a whole than has commonly been supposed. (Thorndike, 1906, pp. 243-246)

Thus, although Thorndike rejected the strong theory of transfer proposed by formal discipline, he did accept a weaker version suggesting that training in a given discipline is only likely to transfer to other situations if there are identical "elements" that can be mapped onto each other.

The ability to transfer knowledge from one experience to another has broad implications across a variety of tasks in an educational setting (e.g., working mathematics problems, learning foreign languages, and applying the rules of science). Transfer also plays an important role in everyday reasoning and decision-making because previous experiences can be utilized to elucidate and benefit subsequent similar experiences. Perhaps because the education environment is one in which successful/unsuccessful transfer is more easily measured quantifiably, much of the research on analogical transfer has focused on problem solving tasks.

In the typical transfer task, problem solvers are presented with either a solved or to-be-solved problem (the source) that is expected to facilitate performance when an analogically similar unsolved problem (the target) is later presented. There is consensus among a number of researchers (e.g., Holyoak & Koh, 1987; Mandler & Orlich, 1993; Needham & Begg, 1991; Novick, 1995; Reeves & Weisberg, 1994) that in order for successful analogical transfer to occur, the problem solver must be able to (a) construct a mental representation of the source and target problems, (b) select the source problem as a relevant analog for solving the target problem, (c) map the relevant components between the source and target, and (d) extend this mapping to generate a solution to the target problem.

In order to mentally represent the source and target problems, the problem solver needs to initially encode various problem components, each of which may have varying degrees of influence on the transfer process. Some researchers (e.g., Gick & Holyoak, 1980, 1983; Gentner, 1983) argue that most relevant to successful transfer is abstracting the deep structure of a problem, which maintains its "essence" irrespective of its content. This is sometimes called the problem's "solution principle" and can be a formula (as in algebra, physics, or logic), a proposition (e.g., "A large force must be broken into smaller elements and summate on a target in order to achieve a goal"), or a rule (e.g., "A figure will be classified as a THOG if, and only if, it contains either the color or shape I have written down, but not both") (Reeves & Weisberg, 1994). In fact, if the solution principle is not encoded, transfer is not expected to occur.

The surface contents of the source and target problems should also be encoded in such a manner that the relations between them are either irrelevant to or instantiate the solution principle. For example, in the THOG rule example above, the specific dimensions of shape and color are essentially irrelevant to solving the task, whereas the relationships among the dimensional values written down, the THOG rule, and a given example of a THOG comprise the essence of the solution principle and thus need to be encoded to facilitate transfer.

A significant proportion of research on analogical transfer has focused on determining the external (i.e., in the problems or experimental manipulation) and internal (i.e., cognitive processes) factors responsible for leading participants to access, select, and apply the correct source analog. Specific external factors have included surface and structural similarity, presence or absence of a hint, and training (e.g., Cheng, Holyoak, Nisbett, & Oliver, 1986; Gick & Holyoak, 1980, 1983; Holyoak & Koh, 1987). Internal factors have included expertise (e.g., Novick, 1988), comparison processes (e.g., Catrambone & Holyoak, 1989; Gick & Paterson, 1992), and schema or rule abstraction (e.g., Gick & Holyoak, 1983). An examination of all these factors was beyond the scope of this experimental investigation. Rather, this research focused on examining the contributions of surface and structural similarity to analogical transfer in a hypothetico-deductive reasoning problem known as the THOG task.

Theoretical Explanations of Analogical Transfer

Reeves and Weisberg (1994) have proposed that analogical transfer can be explained by at least two major classes of theories, each of which makes different assumptions about problem representation and the importance of surface versus deep structure. Two of these theories, Gentner's structure-mapping (Gentner, 1983) and Holyoak's pragmatic schema view (Holyoak, 1985), emphasize the importance of a problem's deep structure in facilitating transfer from a source to a target problem. Gentner and Holyoak agree that surface structure is primarily important in *accessing* the source and *mapping* problem elements between the source and target. They propose, however, that surface similarity is not required for *applying* the analogous solution principle. In contrast, exemplar theories (e.g., Ross & Kilbane, 1997) propose that a solution principle (i.e., the deep structure) is inextricably linked to the surface structure in which it is instantiated. Thus, exemplar theories maintain that surface structure will play an influential role during all stages of analogical transfer.

Gentner's structure-mapping model (1983) condenses the structure of a problem into "elements" and their "relations." In any given problem, there should be detectable surface and structural elements. Surface elements are entities (e.g., color, shape) that sometimes have values (e.g., black, square). Structural elements are those that instantiate relations, such as "either *x* or *y*" or "but not both," among elements. Gentner and Toupin (1986) propose that analogies convey "a system of connected knowledge, not a mere assortment of independent facts" (p. 280). During analogical transfer, matching of elements between a source and target analog can occur at any level but the similarities at the highest level (i.e., those conveying relations among elements) will be chosen for mapping to the target problem. This preference for higher order relations over more surface similarities is known as "systematicity" and reflects Gentner's proposal that true analogies exist only when source and target problems share deep structure (i.e., a system of connected knowledge).

The importance of structural similarity does not imply the irrelevance of surface similarity. In fact, Gentner and Toupin (1986) suggest that surface elements may sometimes be applied during the mapping process because it is *easier* to map when both surface and structural elements and their relations correspond across source and target problems. The emphasis of structure-mapping, however, is on the mapping of similar *structural* elements, not *surface* elements.

Pragmatic schema theory (Gick & Holyoak, 1980, 1983; Holyoak, 1985) is similar to Gentner's structure-mapping theory (1983) in its emphasis on deep structure during the selection and mapping of source to target problems. Holyoak (1985) proposes that analogical transfer is facilitated by strategic schema abstraction, which requires at least two analogs (to compare their similarities and differences) and involves encoding of causally relevant elements. Problem solvers are expected to recognize that two problems (the source and target) share similar causal or goal-oriented elements and this recognition guides abstracting and applying the solution principle (i.e., the schema) from the source to the target problem. The theory is proposed to be "pragmatic" because a schema will contain elements (e.g., goals, causes, constraints) within a problem necessary for solving the problem (i.e., its pragmatic features). Selection of a schema will occur through the process of determining the strength of an analog's representation (based on past usefulness), its level of activation (determined by the amount of structural overlap between a source and target problem), and its direct relevance in accomplishing a problem solving goal (Reeves & Weisberg, 1994). Similar to structure-mapping, pragmatic schema emphasizes that mapping of *structural* similarities is the primary process that facilitates analogical transfer (Holyoak, 1985).

In contrast to emphasizing abstract structure, Brian Ross's (1987) remindings theory proposes that analogical transfer occurs through a process of "remindings" in which retrieval of an earlier problem occurs incidentally, not strategically. This retrieval process is driven by the degree of surface similarity between a source and target problem and not the abstraction of deep structure. According to Ross, the solution principle is inextricably linked to both the source problem and the surface contents in which the principle is instantiated. Thus, remindings theory de-emphasizes the abstraction of deep structure and highlights instead the importance of surface contents. As such, when a target problem, through its high degree of surface similarity, "reminds" the problem solver of an earlier source problem, analogical transfer is more likely to occur.

Evidence has been garnered to support all three theories. This may largely be the consequence of the problems used to test the theories. Gick and Holyoak (1980, 1983) have tested for transfer with "story-like" problems that entail an underlying schematic solution with different thematic contents and Gentner (Gentner & Toupin, 1986) examines story analogies. In both cases, it is the higher-level relations among problem elements that must be abstracted in order for a solution to be achieved whereas surface features are much less relevant to the analogical transfer process. In contrast, Ross (1987; Ross & Kilbane, 1997) primarily examines algebra-type problems and uses surface elements that when properly instantiated into an equation yield a correct solution and conversely, when incorrectly instantiated (or reversed), yield incorrect solutions. For example, he often tests for transfer with permutation problems that involve the division of a specific number of objects among a specific number of people (e.g., computers divided among secretaries). Transfer is most likely to occur when the same correspondences are maintained between the source and target problem and not reversed (e.g., the target problem also divides objects among people as opposed to dividing people among objects).

These three theories have been developed primarily using a different methodology for eliciting analogical transfer than is typically used for studying deductive reasoning tasks. In most analogical transfer experiments, few participants achieve "spontaneous" transfer (i.e., they fail to notice and use the similarities between the source and target problem spontaneously) and, as a consequence, are usually provided with some type of experimental "help" to facilitate transfer. These have included providing more than one source problem to study (e.g., Gick & Holyoak, 1983), instructing participants to compare/contrast two or more structurally similar or dissimilar source problems (e.g., Gick & Paterson, 1992), providing participants with a "hint" to use the source problem in solving the target problem (e.g., Gick & Holyoak, 1980), or using multiple examples to train participants to solve the source problem (Ross & Kilbane, 1997). The goal of such approaches is to determine which factors encourage analogical transfer.

In most deductive reasoning experiments, by contrast, participants are provided with a source problem to solve but are given no training or instruction concerning the correct method for reaching a solution (for exceptions to this, see Klaczynski, Gelfand & Reese, 1989, and Klaczynski & Laipple, 1993). The ability to elicit "spontaneous" transfer with most deductive reasoning tasks is a consequence of correctly solving the source problem and applying this knowledge to the target problem. Thus, whereas both the underlying structure and correct solution are often provided in the typical analogical transfer task, the problem solver working a deductive reasoning task must "discover" the solution principle. The goal of the present study was to investigate how surface and structural similarity contribute to spontaneous transfer in the THOG task, a deductive reasoning problem that is not only difficult to solve but rarely yields analogical transfer. Before describing theoretical explanations for the typically poor THOG task performance, a brief description follows.

The THOG Task

The standard abstract version of the THOG task, developed by Peter Wason (Wason, 1977, 1978; Wason & Brooks, 1979), uses four geometric figures, for example, a black diamond, a white diamond, a black circle, and a white circle. The participant is told that the experimenter has written down one of the colors (black or white) and one of the shapes (diamond or circle) of the given figures. Then the experimenter gives the participant an exclusive disjunctive rule (i.e., *x* or *y*, but not both) that relates the four figures to an arbitrary name, THOG. The rule is "If, and only if, one of the figures includes either the color I have written down or the shape I have written down, but not both, then it is called a THOG." The participant is also told that the black diamond is a THOG. The task is to decide whether each of the other three figures is a THOG, is not a THOG, or that there is insufficient information to make a decision (see Appendix A, Standard THOG Problem, for exact wording).

To solve the problem, the participant must first decide which color-shape combinations *could* be written down. Given the exclusive disjunctive nature of the definitional rule for THOGs and the fact that the black diamond is a THOG, only white and diamond or black and circle could be written down, and the same solution follows in either case. The white circle shares one and only one feature with each combination that could be written down, and the white diamond and black circle share both or neither of the features that could be written down. Therefore, the white circle is definitely a THOG, and the other two figures are definitely not THOGs.

Newstead, Girotto, and Legrenzi (1995) suggest that, at a minimum, participants must understand the exclusive disjunctive rule, generate hypotheses for what could be written down, test each design against these hypotheses, and carry out a combinatorial analysis of the hypothetical consequences (i.e., combining the results of testing the possible hypotheses). Across a number of studies, researchers have determined that participants are capable of understanding and performing each of these steps in isolation (Girotto & Legrenzi, 1989; Marek, Griggs, & Koenig, 2000; O'Brien, Noveck, Davidson, Fisch, Lea, & Freitag, 1990; Smyth & Clark, 1986; Wason & Brooks, 1979). However, the difficulty with the THOG task appears to be the necessity of executing all these tasks consecutively, holding some pieces of information in memory while doing so.

Performance on the standard abstract THOG problem is typically very poor, ranging from 0% – 29% correct ($X = 12.37$, $SD = 7.91$, derived from 11 experimental investigations of abstract versions of the THOG problem). In fact, the incorrect solutions often tend to be mirror images of the correct solution – stating that the white circle is definitely not a THOG and the white diamond and black circle either definitely are or could be THOGs. Thus, for more than 20 years, researchers have attempted to determine why participants reason in this way on the THOG problem and how the structure of the problem might be made more evident.

Theories of Reasoning and the THOG Task

Most theoretical explanations propose that the multi-component complexity of the THOG problem confuses participants and they resort to simplifying it in ways that lead to the dominant error patterns. The common element fallacy explanation, proposed by Griggs and Newstead (1983), suggested that participants assume that "the most commonly occurring attributes in positive instances (are) those that define the concept" (p. 452). With the THOG problem, participants likely perceive the exemplar (black diamond) as defining the concept "THOGness" (even though the rule states differently). As a result, they reason that the black circle and white diamond are THOGs because they each contain at least one of the values/attributes (black, diamond) of the exemplar and that the white circle is not because it includes neither (Griggs and Newstead label this error Type A). Thus, the common element fallacy explanation suggests that participants wrongly assume what the relevant values are, but then reason logically from this assumption (Griggs & Newstead, 1983).

A matching bias explanation, on the other hand, proposes that when the complexity of the problem overwhelms participants, they adopt a non-logical matching strategy (Griggs & Newstead, 1983). Participants observe which figures include values that match the exemplar. If there is a match, the design is labeled a THOG; otherwise it is not. Thus, the white circle clearly is not because it contains neither value. In addition, because the white diamond and black circle each contain only one of the values, participants are unsure of how to respond and select the indeterminate response for these two figures (labeled a Type B error by Griggs and Newstead). Thus, this explanation suggests that participants are not using the disjunctive definitional rule (as is proposed by the common element fallacy explanation), but are relying on a simple perceptual matching strategy to solve the problem. Griggs and Newstead (1983) designed three versions of the THOG problem to test whether common element fallacy or matching bias provided a more parsimonious explanation for the frequency of Type A and B errors (which Wason and Brooks, 1979, originally labeled "intuitive" errors). Results from three experiments, however, failed to unequivocally resolve the primacy of a matching bias or common element fallacy explanation.

More recently, Newstead and Griggs (1992) have proposed a "confusion theory" explanation for the patterns of performance typically exhibited with the THOG problem. They suggested that the combined tasks of generating hypotheses, holding them in memory, and simultaneously testing them surpass working memory limitations (see also Newstead et al., 1995). The response to this confusion is to simplify the task by incorrectly assuming that the values of the exemplar (i.e., the black diamond) are the values that have been written down. The frequency of both Type A and Type B "intuitive" errors can then be attributed to some type of elementary matching heuristic – that is, matching each design to the known exemplar and responding in accordance with the closeness of the match. Evidence supporting confusion theory has been increasing as a number of studies have revealed that reducing this confusion by facilitating separation of the properties of the exemplar from the properties written down does lead to improved performance (e.g., Girotto & Legrenzi, 1989, 1993; Griggs, Koenig, & Alea, 2001; Needham & Amado, 1995; O'Brien et al., 1990).

To understand why separation is important to facilitating performance, a proposal by O'Brien et al. (1990) needs to be considered. O'Brien et al. argued that participants may have difficulty during the initial encoding of the standard THOG problem because the written-down values, the THOG rule, and the exemplar all refer to the same colors (black and white, typically) and shapes (diamond and circle, typically). Given the complexity of the THOG problem, participants may have difficulty encoding (and possibly storing) these similar pieces of information separately. As a consequence, they may conflate the problem information to reduce its complexity. Such conflation would likely produce a simplistic interpretation of the problem that leads to the frequently observed intuitive errors (i.e., that black diamond represents *both* the exemplar and the written-down properties).

This tendency to conflate color and shape is indicated by some findings in concept identification research. As pointed out by Girotto and Legrenzi (1989), this conflation may be difficult to resist because the dimensions of a THOG (color and shape) have been shown in concept studies to be resistant to separation and conducive to *inclusive* disjunctive interpretations (*x* or *y*, or *both*) (Ketchum & Bourne, 1980). Thus, versions of the THOG problem that *decrease* conflation may reduce the likelihood that problem solvers will confuse the values of the exemplar with those written down, thereby facilitating performance.

Facilitation on the THOG Task

Recently, two versions of the THOG problem, the Blackboard THOG (an abstract version developed by O'Brien et al., 1990) and the Pythagoras THOG (a thematic version developed by Needham & Amado, 1995) have produced some of the highest levels of correct performance (range 68% – 73%) in over twenty years of research on problems that maintain the THOG task's underlying structure (Griggs et al., 2001; Koenig & Griggs, 2001). The two problems have produced these high levels of performance in quite dissimilar ways. A description of each problem and an explanation of its facilitating factors will clarify this distinction.

The Pythagoras THOG

In the narrative of the Pythagoras THOG (see Appendix B, Pythagoras THOG, for exact wording), the color-shape combination is written down by a specific character (Professor Pythagoras) for a specific purpose (a scheme that allows his assistant to classify new geometric figures as THOGs or not THOGs) and put in a specific place (on an index card taped to a wall over the assistant's desk whereas the four geometric figures are on the desk). In this version, the THOG rule becomes: "A figure will be classified as a THOG if and only if either its color matches the color name on the card above, or its shape matches the shape name on the card above, but not both."

According to Needham and Amado (1995), this narrative structure separates the values of the positive exemplar from those possibly written down because the "story" provides a context in which one character (the professor) writes down the defining values for a specific purpose but another character (the assistant) uses those values in applying the rule. The Pythagoras THOG problem also includes a hypothesis generation request (i.e., asking participants to hypothesize the combinations Professor Pythagoras could have written down that result in the exemplar being labeled a THOG) before asking participants to classify the remaining three figures. However, because of supporting findings for another narrative problem and past studies indicating that hypothesis generation alone does not facilitate performance (e.g., Newstead & Griggs, 1992; Smyth & Clark, 1986; Wason & Brooks, 1979), Needham and Amado (1995) proposed that this request might not be necessary to produce facilitation. They did not, however, directly test this assumption.

In two experiments, Needham and Amado (1995) observed an average of 62% correct for the Pythagoras THOG. Griggs et al. (2001) replicated this level of performance (68% correct) on two versions of the Pythagoras THOG – one that included the hypothesis generation request and one that did not. Thus, as Needham and Amado initially suggested, the facilitation observed with the Pythagoras THOG may be the consequence of separating the values of the exemplar from the values written down and not the result of requesting participants to generate hypotheses for the written down combinations.

Needham and Amado (1995) did not realize that the Pythagoras THOG contained another possible source for the observed facilitation. In the problem statement, each of the four geometric figures is explicitly referred to as a numbered figure (i.e., Figure 1, Figure 2, Figure 3, and Figure 4). Normally the geometric figures are presented visually without any labels. In addition, instead of describing the exemplar by its color and shape names (i.e., the black diamond is a THOG), it is identified by a figure number (i.e., Figure 1 is a THOG). Thus, by providing the designs with figural labels instead of identifying them by color and shape, the Pythagoras THOG may have led participants to not conflate (i.e., to separate) the color and shape information and thus reduced the likelihood that they would confuse the values of the exemplar with those written down, thereby facilitating performance.

The Pythagoras THOG thus included *two* features that may have been responsible for and/or interacted to produce the observed facilitation: figural labeling and narrative structure. Across three experiments, Griggs et al. (2001) systematically examined the influences of these features independently, in combination, and with the hypothesis generation request (see Appendix B, Narrative THOG, Label THOG, Narrative + Label THOG, Narrative + Hypothesis Generation THOG, Label + Hypothesis Generation THOG). Their results indicated that figural labeling alone produced significant facilitation (47% correct), whereas correct performance on the Narrative THOG (44% correct) was only marginally significantly greater than the Standard THOG, *(p = .069)*.

In Experiment 2 (Griggs et al., 2001), correct performances on the Narrative + Hypothesis Generation THOG and Label + Hypothesis Generation THOG were both found to be significantly greater (61% and 55%, respectively) than the Standard THOG ($p < .05$). Although performance was better when two factors were combined, it was not significantly better than when the hypothesis generation request was absent, as in Experiment 1. However, in Experiment 3, it was revealed that labeling combined with narrative structure (without hypothesis generation) resulted in substantial facilitation (68% correct, $p < .01$) when compared to the Standard THOG. This level of correct performance was not, however, significantly greater than any other problems in Experiments 1 and 2. The results of these three experiments revealed that, as Needham and Amado proposed (1995), hypothesis generation was not necessary to obtain facilitation. However, given the facilitation produced by figural labeling, it appears that narrative structure is not the only feature of the Pythagoras THOG that facilitates separating the exemplar from the written down combinations.

The Blackboard THOG

The Blackboard THOG (O'Brien et al., 1990) is notably different from the Pythagoras THOG in how it facilitates performance. In this version of the THOG task, the participant is told that one color-shape combination is written down on the *left-hand side* of the experimenter's blackboard and the other remaining color-shape combination is written down on the *right-hand side* of the blackboard. The THOG rule then becomes, "A figure will be classified as a THOG if, and only if, it includes either the color written down on the left-hand side of the blackboard, or the shape written down on the left-hand side of the blackboard, but not both." (see Appendix B, Blackboard THOG, for exact wording.) In the standard THOG problem, the participant is told only that a color-shape combination is written down. No location information is provided. Also, the remaining color-shape combination is not even mentioned in the problem statement and thus may not be included in a participant's problem representation.

One means of conveying problem structure is through a visual representation, which can be especially useful in solving problems of a spatial nature (Beveridge & Parkins, 1987). Koenig and Griggs (2001) proposed that the Blackboard THOG might lead participants to construct a quasi-visual representation of the binary, symmetric structure of the THOG problem (i.e., a representation that included the combination *written* down, which *is* mentioned in the rule, and the combination *not written* down, which *is not* mentioned in the rule) because a blackboard is a stimulus onto which they could "mentally" or "physically" write both parts of the problem's structure. They compared performance on the standard THOG, the Blackboard-Control THOG (a version that *did not* include information about the *right-hand side* of the blackboard), and the Blackboard THOG. As expected, correct performance on the Blackboard THOG (68% and 73% in a replication) was significantly better than both the Blackboard-Control THOG (44%) and the standard THOG (24%) problems.

To explore how the quasi-visual manipulation facilitated problem representation, Koenig and Griggs examined each participant's problem sheet (2001). The types of notations made on the problem sheets suggested that providing a quasi-visual context led participants to construct a vivid spatial representation of the problem that facilitated task performance. Specifically, in *both* Blackboard conditions (and the replication) there were many notations of blackboard-like diagrams, "left" and "right" labels for color-shape combinations, and color-shape combinations oriented in a left-right fashion on the problem sheet. These notations indicated that participants were likely reasoning about all possible combinations and their relationship to both the exemplar and the THOG rule (i.e., the solution principle). Without these facilitating problem features, participants in the standard THOG problem condition provided none of these types of notations.

Results from the Pythagoras THOG and Blackboard THOG problems suggest that the majority of participants can solve the THOG task if the solution principle is made more salient. With the Pythagoras THOG, this facilitation appears to occur through the contributions that figural labeling and narrative structure make to separation. For the Blackboard THOG, facilitation may occur as a consequence of educing a quasi-visual representation of the possible combination written down and the companion combination not written down. The question that has not been answered, however, is whether or not participants were truly abstracting the THOG problem's underlying structure in these two versions. One means of testing this is through analogical transfer.

Analogical Transfer and the THOG Task

In seeking to facilitate performance on the THOG problem, researchers have generally sought to make the problem's structure more apparent through a variety of manipulations that might transfer to the standard THOG problem. Wason and Brooks (1979) attempted to produce transfer in two experiments. In their first experiment (Constructed CHUZ), participants were instructed to write down a shape and color and then classify four designs as a function of these written down properties and the THOG rule. Whereas all participants successfully classified the designs, no significant transfer was obtained when they subsequently worked the standard THOG problem. In a second experiment, participants were asked to identify which shape and color combinations the experimenter could have written down given that the Green Square was a CHUZ (THOG). Participants who correctly provided all hypothesized features (i.e., were "spontaneously correct") worked a standard CHUZ problem followed by the standard THOG. Those who failed to generate the correct hypotheses were provided the correct answers and a detailed explanation concerning correctness. These “not spontaneously correct” participants then worked the CHUZ and THOG problems. No significant transfer, however, was obtained for either the “spontaneously correct” or “not spontaneously correct” participants.

Wason and Brooks (1979) proposed that the Constructed CHUZ failed to produce transfer because participants conducted the combinatorial analysis with only one set of properties – those that the *participants* had written down. As a consequence, this made the critical shape and color values non-hypothetical, unlike the THOG problem in which participants *do not* know the values that could be written down. However, when the hypothetical nature of the problem was made more evident in the second experiment, solution rates still showed no improvement. Participants appeared to abstract only part of the solution principle of the THOG task – the hypothesis generation task. They seemed to have difficulty following this up with the combinatorial analysis, an essential component of the solution principle. As Wason and Brooks (1979) concluded, “It may be peculiarly difficult to reason about hypothetical possibilities to reach determinate conclusions” (p. 88).

Research by Griggs and Newstead (1982; 1983) followed up the Wason and Brooks (1979) study by attempting to determine “the source of the difficulty” and the "source of intuitive errors" (Type A and B errors) on the THOG problem. In their 1982 paper, they described four experiments with thematic and abstract versions of the THOG problem that did produce facilitation. This facilitation was achieved primarily by making the two sides of the problem's binary, symmetric structure more obvious. The thematic version that preceded the standard THOG involved the types of drugs permissible to give patients on a daily basis (calcium or potassium in the form of injection or tablet). This problem (labeled the Rephrased Drug, see Figure 1-1 below), however, did not transfer to the standard THOG. The reason for this failure most likely lies in those features of the thematic version that did not map onto the standard THOG problem (see Figure 1-2 below).

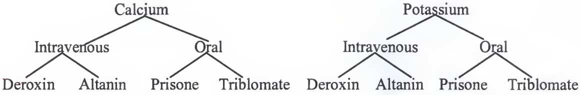

Figure 1-1. Binary structure of the Rephrased Drug problem

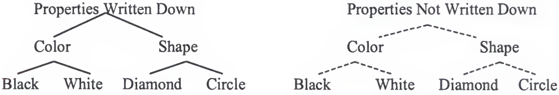

Figure 1-2. Binary structure of the standard THOG problem

A comparison of Figures 1-1 and 1-2 illustrates that the structural tree of the Rephrased Drug problem included additional labels that are not a part of the THOG problem. The standard THOG problem would have had to include unique labels for both possible color and shape combinations – those written and not written down – in order for this mapping to have been more consistent. (The dashed lines indicate the structure not mentioned in the THOG problem.) Thus, because the structural similarity that Griggs and Newstead (1982) attempted to obtain did not map exactly onto the standard THOG problem, participants may not have been able to use the Rephrased Drug problem to enhance their understanding of the THOG problem's underlying structure.

In their 1983 paper, Griggs and Newstead described their attempts to determine the source of intuitive errors typically found on the standard THOG problem. Of particular interest is their first experiment, in which they presented participants with the NOT-THOG problem, a version of the standard THOG in which the exemplar (the black diamond) was labeled as *not* a THOG. Griggs and Newstead argued that the "not a THOG" wording should inhibit participants from reasoning that the exemplar and written down properties are the same. If this wording produced improved logic, it would be evidenced by transfer to the standard THOG. As expected, performance on the NOT-THOG was significantly better than performance on the standard THOG. However, any improvement in logic or problem understanding failed to be evidenced because significant transfer to the standard THOG problem did not occur.

Following the work of Griggs and Newstead (1983), Smyth and Clark (1986) attempted to achieve transfer with a realistic THOG problem by incorporating a family relationship that mapped onto the concept "THOG." They proposed that the step-sister relationship (which they called "half-sister") was a concept that mirrored the exclusive disjunctive rule in the THOG problem (i.e., a half-sister is the daughter of my mother or my father, but not both). They hypothesized that by developing a THOG problem that took advantage of this similarity, they might lead participants to perform more correctly with realistic content. At the same time, this realism might be one of the ways to reduce problem difficulty and encourage the hypothetico-deductive reasoning strategies needed to solve the problem. In doing so, the underlying structure of the task would be revealed in a way that would transfer to the standard abstract THOG problem.

In two experiments, Smyth and Clark (1986) revealed that participants understood the step-sister relationship and could work a half-sister version of the THOG problem only when it did not include the exclusive disjunctive rule or emphasize the unknowns in the problem. In both cases, however, no transfer to the standard THOG problem was elicited. In three subsequent experiments, problem manipulations intended to enhance problem solving strategies were added, such as (a) asking what could have been written down, (b) telling participants that the exemplar was NOT the half-sister, and (c) stepping participants through generating the hypotheses and then doing the combinatorial analyses that would follow. Across all but the first experiment, participants worked three problems each (either two standard THOGs with a half-sister problem inserted between them or two half-sister problems with a standard THOG problem inserted in the middle). However, regardless of the experimental manipulation incorporated, no significant analogical transfer was obtained.

More recently, investigators have focused on producing facilitation by separating the values of the exemplar (the black diamond) from the possible values written down. Needham and Amado (1995) constructed two thematic versions of the THOG problem (Pythagoras, Executioner) intended to achieve this separation. In the Executioner problem, the Mogul character writes down on a card whether or not (a) an individual is male or female and (b) is from the Acady or Nurdu clan and then gives this card to the Royal Executioner. The Royal Executioner tapes the card to the door of the death chamber over the inscribed "THOG-like" royal order: "A person will be executed if and only if EITHER their clan matches the clan name on the card above, OR their sex matches the sex given on the card above, BUT NOT BOTH." Using the information on the card and the royal order, the Executioner determines which of four individuals will be executed. Participants were told which individual had been executed (i.e., the exemplar) and then were asked to determine if any of the others had or had not been executed or if they couldn't tell.

Like the Pythagoras problem, Needham and Amado (1995) included a hypothesis generation task (i.e., a request to provide what the Mogul could have written on the card) before asking participants to complete the "Execution (THOG)" classification for the remaining three individuals. They also developed three additional versions (No Mogul, No Executioner, No Question) in order to determine the importance of each of these problem features in producing facilitation (i.e., the character who writes down the features, the character who applies the rule, and the hypothesis generation request).

In Experiment 1, Needham and Amado (1995) determined that the Pythagoras, Executioner, No Executioner, and No Question variants all produced significant facilitation as compared to performance on the standard THOG (correct performance ranged from 42% – 52% as compared to 9% on the standard). In a follow-up experiment, they tested for transfer from both the Executioner and Pythagoras problems to the standard THOG problem. Only the Pythagoras problem produced both significant facilitation and transfer. Fifty percent of the participants (12/24) who first worked the Pythagoras problem answered the THOG problem correctly, compared to only 9% (2/23) of those who first worked the Executioner problem. Needham and Amado (1995) concluded that although a thematic version was needed to produce facilitation, the geometric figures (which the Executioner lacked) were essential in producing transfer.

Needham and Amado's (1995) transfer effects need to be reconsidered. It is not clear from these results that participants were truly transferring the THOG problem's underlying deep structure when they solved the transfer problem. Skepticism arises from the figural designs used in their transfer task. In the Pythagoras THOG, the black diamond is identified as a THOG and 62% of participants were able to correctly classify the remaining figures. However, it should be noted that in developing the transfer standard THOG problem, the *black circle* was identified as a THOG. Absent the context of an overlying theme that made the solution principle more evident, participants may have relied upon a simple surface similarity heuristic.

Specifically, participants may have noticed that the "to be classified" THOG (white circle) in the Pythagoras THOG problem contained the "opposite" features of the exemplar (black diamond). Therefore, when lacking the facilitating feature of a thematic structure, participants may simply have relied upon the surface similarity between the problems and this would, in fact, produce correct performance (i.e., the participants would select *white diamond* as the correct "opposite" of *black circle*). This outcome seems plausible given that participants worked the standard THOG problem immediately after the Pythagoras THOG and their memory of selecting the white circle should have been easily accessible.

Summary

In seeking to facilitate comprehension of the THOG task, researchers have attempted to make the problem's underlying structure more apparent through a variety of manipulations. These have included (a) thematic narratives of known disjunctive relationships that *did* map onto the THOG problem's structure (e.g., the half-sister relationship; Smyth & Clark, 1986), (b) thematic narratives of disjunctive concepts that *did not* map onto the THOG problem's structure (e.g., permissible/not permissible drug combinations; Griggs & Newstead, 1982) and (c) hypothesis generation requests (e.g., Wason & Brooks, 1979). Although several studies have utilized abstract and thematic problems that mapped onto the THOG's underlying structure, very few have successfully revealed any substantial facilitating effects. More recently, the Blackboard THOG has demonstrated its ability to facilitate high levels of correct performance (Koenig & Griggs, 2001) and the Pythagoras THOG has demonstrated its ability to produce both facilitation *and* analogical transfer (Needham & Amado, 1995). Thus, an examination of how these problems facilitate comprehension of the THOG task's underlying structure was deemed appropriate for further experimental investigation.

CHAPTER 2
OVERVIEW OF DISSERTATION EXPERIMENTS

Producing facilitation or transfer with THOG problems that are structurally isomorphic to the original abstract THOG task has challenged researchers for over twenty years. The question that remained unanswered was whether or not problems that produced significant improvements in performance have done so as a consequence of helping participants abstract the THOG problem's solution principle. One method for ascertaining this is to test for analogical transfer.

The assumption underlying attainment of analogical transfer is that participants abstract essential elements of the solution principle from a source problem and apply them to a target problem. Determining which elements in a THOG problem are most likely to convey its underlying structure should be helpful in improving our understanding of whether or not participants can reason hypothetically and deductively (i.e., are capable of formal operational thought, Piaget, 1972) – an ability that has been questioned given the typically poor performance on this task. This research was designed to explore this issue by examining the influences of surface and structural similarity on analogical transfer.

Previous research demonstrates that facilitation can be obtained when participants work versions of the standard abstract THOG problem that *reduce* the likelihood that participants conflate the problem information, fail to generate hypotheses for the possible written-down combinations (labeled the "parents" of the exemplar by Girotto & Legrenzi, 1993), or assume that the exemplar and the features written down are the same. In other words, facilitation is most frequently obtained when participants abstract at least part or all of THOG problem's underlying structure. Factors that have produced this include (a) providing labels for the to-be-classified figures and the exemplar (e.g., Newstead & Griggs, 1992), (b) combining hypothesis generation with other facilitating features (e.g., Girotto & Legrenzi, 1993), and (c) separating the exemplar from the properties written down via a thematic narrative (e.g., Pythagoras THOG, Needham & Amado, 1995) or a quasi-visual representation (e.g., Blackboard THOG, O'Brien et al., 1990).

A review of the THOG literature indicated that only two problems have produced substantial facilitation (range 62% to 73% correct) without making significant changes in the structural features of the THOG problem – the Blackboard THOG (Koenig & Griggs, 2001; O'Brien et al., 1990) and the Pythagoras THOG (Griggs et al., 2001; Needham & Amado, 1995). Both problems have unique features (described earlier) that made them potential candidates for producing transfer to the standard THOG problem. In addition, their ability to produce such high levels of facilitation may be evidence that they are the problems most capable of conveying the THOG problem's underlying structure.

The primary purpose of this research was to explore whether or not analogical transfer to the standard THOG problem could be produced as a consequence of surface or structural similarity to a source problem. The Blackboard THOG and Pythagoras THOG problems were selected as source problems for three reasons: (a) The Pythagoras THOG had previously yielded transfer, (b) both problems had produced high levels of facilitation, and (c) each problem contained distinctive features useful for teasing apart those structural elements necessary for producing analogical transfer.

In the first three experiments, gradual changes in surface similarity were introduced to determine whether or not any observed transfer effects occurred as a consequence of surface similarity between the source and target problems. By examining separately the influences of the values (e.g., black, white, square, circle) and the dimensions (e.g., shapes, colors) mentioned in the THOG problem statement, a better understanding of the contribution of surface similarity to analogical transfer would be obtained. Support for Gentner's structure mapping (1986) and Gick and Holyoak's (1980; 1983) pragmatic schema theory would be garnered if analogical transfer could be obtained in the presence of decreasing surface similarity. Whereas if analogical transfer could be produced only in the presence of high surface similarity, more support for Ross's (1987) remindings theory would be obtained.

The contribution of structural similarity to analogical transfer was explored in Experiment 4 with three versions of the Pythagoras THOG problem. This experiment allowed an examination of those factors necessary for producing *both* facilitation and transfer. Structural similarity effects with the Blackboard THOG were not explored given its failure to produce significant analogical transfer following a modest change in surface features.

This research differed from previous work in two ways. First, most of the empirical work on the THOG problem has used facilitation as the criterion for establishing understanding of the task. By using transfer as a stricter performance criterion, evidence that participants had successfully abstracted the underlying structure of the standard THOG problem would be empirically stronger. Second, unlike the typical problem solving approach to transfer, participants were *not* told either how to solve the problem, to use the source problem to help solve the target problem, or the correctness of their responses. This conservative approach was adopted to determine which elements in the standard THOG task are essential for producing sufficient problem representation and, thus, most likely to produce "spontaneous" analogical transfer.

CHAPTER 3
DESIGN AND METHODOLOGY OVERVIEW

Participants

Four hundred sixty-six University of Florida introductory psychology students took part in this research in order to fulfill an experimental participation requirement for the course. Experiments were conducted in groups of 12 or fewer, and the experimenter conducted all recruiting and data collection. Participants were recruited through an online sign-up web page that displayed all currently available psychology experiments. No participant was allowed to sign-up for more than one experimental session.

Procedure

The methodology for running experiments was consistent throughout all data collection. Written informed consent was obtained and general instructions were provided orally in advance of distributing the first problem. Participants were randomly assigned to work either one or two problems as a function of which problem conditions were being conducted in a given experiment. In addition, participants were given ten minutes to work each problem. Following completion of each experiment, participants were provided with information concerning a debriefing session (see Appendix C, Additional Experimental Materials).

Materials

All problems were presented on individual sheets of paper. For each problem tested, three orders of the to-be-classified figures (e.g., black circle, white circle, white square) were created (e.g., □ ○ ● vs. □ ● ○). In addition, when a participant was given a source and target problem, the order of the to-be-classified figures differed for each problem.

Similarity Questionnaire

In all transfer conditions, participants were provided with a brief open-ended questionnaire to answer following completion of the target problem. This questionnaire requested participants to describe any noted similarities between the source and target problems. They were also asked to denote if and how the source problem facilitated solving the target problem. Given the variability in the types and frequencies of responses to the similarity question, meaningful statistical comparisons among the different problem conditions were not plausible. Therefore, only summaries of responses that occurred relatively frequently or that were useful for interpreting patterns of performance are provided.

Error Patterns

The total number of possible answer choices in the THOG problem is 27 (3 designs X 3 classification choices X 3 answer selections). As a consequence, there will generally be significant variability in the error patterns in any given experiment. Thus, for each experiment in this study, each sheet (i.e., each source and target problem) was examined for the presence of the six most commonly occurring error patterns. These include classifying all figures as not THOGs, all figures as THOGs, all figures as indeterminate, and the three patterns described below in Table 3-1. A more detailed summary of error patterns in each experiment is provided in Appendix D.

Table 3-1. Common error patterns for the standard THOG problem

Error Pattern[a]	Exemplar Given	White Circle Classification	Black Circle Classification	White Square Classification
A	Black square	*Not a THOG*	*Is a THOG*	*Is a THOG*
B	Black square	*Not a THOG*	*Can't tell*	*Can't tell*
Near Insight	Black square	*Is a THOG*	*Can't tell*	*Can't tell*

[a] The correct solution is "White Circle is a THOG, Black Circle is not a THOG, White Square is not a THOG."

CHAPTER 4
EXPERIMENT 1 – TESTING FOR TRANSFER

Introduction

The purpose of this experiment was to test for transfer with two problems that have demonstrated substantial facilitating effects, the Blackboard THOG (O'Brien et al., 1990) and the Pythagoras THOG (Needham & Amado, 1995). In previous research, Needham and Amado observed transfer with the Pythagoras THOG using a target Standard THOG problem in which only the shape of the exemplar was changed. This methodology was adopted in this first experiment to determine if these results were replicable. In addition, the Blackboard problem was examined for its ability to produce transfer given its previously high levels of facilitation (Koenig & Griggs, 2001).

Design and Methodology

Participants

Seventy-five participants were recruited and randomly assigned to the Standard THOG ($n = 25$), Blackboard THOG ($n = 25$), and Pythagoras THOG ($n = 25$) problem conditions. This sample size was selected because previous research on the Blackboard THOG (Koenig & Griggs, 2001) and Pythagoras THOG (Griggs et al., 2001; Needham & Amado, 1995) problems has shown average correct performance in the range of 52% to 73% on these problems utilizing similar sample sizes and yielding significant differences from the Standard THOG between $p < .01$ and $p < .001$ significance levels.

Target Power

With an expected Source Standard THOG percent correct of 12%, an expected transfer effect of 45% correct on the target problems following the Blackboard THOG and Pythagoras THOG, and a sample size of 25 per condition, target power was .70.

Materials

All source and target problems were created using the same dimensions (shape, color) and values (black, white, square, circle) described previously in the Materials section of Design and Methodology Overview. In the source problem, the Black Square was designated as the exemplar. In the target problem, the Black Circle was designated as the exemplar.

Procedure

Participants were first provided ten minutes to work the source problem. When ten minutes had passed, this problem was collected and the target problem was distributed. Following a second ten-minute time period, the target problems were collected. Participants were then given a sheet of paper containing a written request to describe any similarities they observed between the source and target problem and to explain whether or not these similarities helped them solve the target problem.

Transfer Problem Order Conditions

Source problem → target problem

Blackboard THOG → Target Standard THOG

Pythagoras THOG→ Target Standard THOG

Source Standard THOG → Target Standard THOG

Results

Facilitation and Transfer

The percent corrects for all source and target problems are detailed below in Table 4-1. Comparisons among all source problems revealed that correct performance on the Source Standard THOG problem was significantly lower than correct performance on the Blackboard THOG, χ^2 (1, $N = 50$) = 10.78, $p = .001$, and the Pythagoras THOG, χ^2 (1, $N = 50$) = 20.78, $p < .001$, problems. Correct performance on the Pythagoras THOG was not significantly better than the Blackboard THOG, χ^2 (1, $N = 50$) = 2.23, $p = .136$. Comparisons among target problems revealed that correct performance on the Target Standard THOG was significantly better when it followed the Pythagoras THOG (52% correct), χ^2 (1, $N = 50$) = 7.22, $p = .007$ and the Blackboard THOG (48% correct), χ^2 (1, $N = 50$) = 5.88, $p = .015$ than when it followed the Source Standard THOG (15% correct).

Table 4-1. Percent correct on source and target problems in Experiment 1

Problem	Source problem	Target THOG problem
Pythagoras THOG	76% (19/25)	52% (13/25)
Blackboard THOG	56% (14/25)	48% (12/25)
Blackboard Replication	44% (11/25)	44% (11/25)
Standard THOG	12% (3/25)	15% (4/25)

Given that this is the first experimental finding of transfer with the Blackboard THOG problem, this condition was replicated with 25 additional participants. A comparison among source problems revealed that correct performance for the Blackboard THOG replication was significantly higher than the Standard THOG, χ^2 (1, $N = 50$) = 3.95, $p = .047$ and significantly lower than the Pythagoras THOG, χ^2 (1, $N = 50$) = 8.12, $p = .004$. A comparison among target problems revealed that correct performance on the

Target Standard THOG was significantly better when it followed the Blackboard THOG replication (44%) than when it followed the Standard THOG, χ^2 (1, *N* = 50) = 4.67, *p* = .031.

Error Patterns

The most common errors in Experiment 1 were "all are THOGs" and Intuitive A. Significantly more participants classified all figures as THOGs in the Standard THOG condition (*n* = 9) than in the Pythagoras THOG condition (*n* = 1), χ^2 (1, *N* = 100) = 7.11, *p* = .008. Similarly, Intuitive A errors occurred more frequently in the Standard THOG condition (*n* = 16) than in the Blackboard THOG condition (*n* = 6) and Pythagoras THOG condition (*n* = 6), χ^2 (1, *N* = 100) = 5.83, *p* = .016. In the Standard THOG condition, the majority of the "all are THOGs" errors occurred for the target problem. In contrast, Intuitive A errors occurred primarily because participants made these same selections for both the source and target problems. (A more detailed summary of error patterns is provided in Appendix D.)

Similarity Questionnaire

Most participants (89%), irrespective of problem performance, noticed the similarity between the source and target problems in structure, shapes/colors, classification instructions, and/or classification rule. Eighty-three percent of participants who successfully achieved transfer either stated or made notations indicating they had used the same strategy on both problems. This compared with only 33% of those who failed to achieve transfer. In addition, 46% of participants who achieved transfer noted the second problem was a variation of the first, whereas only 13% did so among those who failed to achieve transfer. (See a summary of responses in Table 4-2 below.) Thus, participants clearly noticed both the surface and structural similarities between the source and target problems. It appears, however, that only those participants who applied a successful strategy across both problems were those most likely to achieve analogical transfer.

Table 4-2. Responses to similarity questionnaire in Experiment 1

Response to similarity questionnaire [a]	Standard		Blackboard[b]		Pythagoras	
	Transfer		Transfer		Transfer	
	Yes	No	Yes	No	Yes	No
Same shapes and colors	1/4	12/21	7/12	10/13	8/13	5/12
Similar structure	1/4	5/21	4/12	2/13	0/13	5/12
Same classification rule	1/4	9/21	5/12	8/13	12/13	8/12
Same classification instructions	2/4	8/21	2/12	5/13	4/13	5/12
Similarity helped [c]	1/4	10/21	3/12	7/13	8/13	4/12
Similarity did not help [c]	0/4	5/21	2/12	3/13	1/13	1/12
Used same strategy on both problems	3/4	4/21	9/12	5/13	12/13	6/12

[a] Values in the table reflect only those participants who provided the responses summarized. Some participants provided several responses, whereas others only provided one or two.

[b] Given that transfer effects were similar in the Blackboard and Blackboard Replication conditions, only the questionnaires from the Blackboard condition were included in this summary table.

[c] Responses to whether or not the similarity between problems helped in solving the transfer problem were provided by only 59% of participants (range of 14 – 16 across conditions).

Notations

Participants' problem sheets were examined for any additional notations beyond the circling of responses. (See Table 4-3 below for a summary of these notations.) Across all problem conditions, significantly more participants who achieved transfer (90%, 26/29) provided notations on both problem sheets than did participants who failed to achieve transfer (41%, 19/46), χ^2 (1, $N = 75$) = 17.33, $p < .001$. In addition, except in the Standard THOG condition, the most successful participants were those who had used the same strategy on both problems.

Most additional notations were found on the Blackboard THOG problem sheets. In this condition, 81% of participants who correctly solved either the Blackboard THOG, the Target Standard THOG that followed the Blackboard THOG, or both, had made additional notations that included (a) "left" or "right" labels, (b) blackboard-type drawings, and/or (c) labels of figures (e.g., white square) written in a left-right orientation on the problem sheet. These types of notations were completely absent in the Pythagoras THOG condition and the Source Standard THOG condition.

In the Source Standard THOG condition, 75% (15/20) of completely incorrect participants (solved neither the source or target problem) made no additional notations on either problem sheet beyond the circling of responses. In contrast, all participants ($n = 5$) who correctly solved either the Source, Target, or both Standard THOG problems made some type of additional notation. Two of the participants who achieved transfer had written the "parents" (i.e., the possible written-down combinations) of the THOG exemplar. Among the few participants ($n = 12$) who made additional notations on one or both problem sheets, 50% labeled the exemplar as a THOG and/or labeled the values of each figure, neither of which may be particularly helpful in understanding the solution principle. In fact, labeling figures may have reduced the likelihood that participants would have hypothesized about the values separately (i.e., black *or* circle vs. black circle).

The Pythagoras THOG elicited little additional notation beyond writing the "parents" of the THOG on the Target Standard THOG problem. Of those participants who correctly solved the Pythagoras THOG or achieved transfer, 79% and 92%, respectively, wrote the "parents" of the exemplar on the Target Standard THOG problem. Only one participant who *incorrectly* solved the Pythagoras THOG problem also made this notation on the Target Standard THOG problem.

Table 4-3. Notations on problem sheets in Experiment 1

Notations [a]	Standard		Blackboard		Pythagoras	
	Transfer		Transfer		Transfer	
	Yes	No	Yes	No	Yes	No
No notations provided	0/4	15/21	1/12	2/13	0/13	0/12
Label exemplar with "THOG" or color/shape combination on one problem only	0/4	1/21	2/12	1/13	3/13	0/12
Label exemplar with "THOG" or color/shape combination on both problems	0/4	2/21	2/12	3/13	0/13	0/12
Both hypotheses ("parents") provided on first problem only	0/4	2/21	1/12	2/13	2/13	8/12
Both hypotheses ("parents") provided on both problems	2/4	0/21	6/12	3/13	12/13	5/12
"Blackboard-type" drawing, left/right labels, left-right orientation of values on first problem only	0/4	0/21	6/12	6/13 [b]	0/13	0/12
"Blackboard-type" drawing, left/right labels, left-right orientation of values on both problems	0/4	0/21	3/12	2/13	0/13	0/12

[a] Because of the variability in responses, only notations provided at least 20% of the time in a single condition were described.

[b] Included among these values are 3 participants who correctly solved the Blackboard problem but failed to achieve transfer.

Experiment 1 Conclusions

The results from this experiment demonstrated that facilitation and transfer were possible to obtain with THOG problems that made elements of the solution principle more evident. The notations in the Pythagoras THOG condition suggested this occurred by making the necessity of reasoning about both possible "parents" of the THOG exemplar more evident through hypothesis generation. It is noteworthy that 92% of participants achieving transfer in the Pythagoras THOG condition provided this notation on *both* problems, suggesting that this specific solution strategy transferred to the target problem. However, this strategy was not entirely successful for all participants given that 42% of participants who *failed* to achieve transfer had also made these notations on both problems.

The notations in the Blackboard THOG condition suggested that providing a quasi-visual context elicited reasoning about both sides of the problem's structural tree (i.e., reasoning about both the written and not written down values). As one participant who achieved transfer noted, "The 'blackboard' example was better for me because it gave me the mental image I needed to construct the grid. I just made another grid for the second problem which met the criteria, and it was much easier." However, the number of participants in this experiment relying on strategies educed by the blackboard context (e.g., blackboard-type drawings, left or right labels) was not as high as Koenig and Griggs (2001) observed -- 68% vs. 94%, respectively. It is worth noting that 48% of participants in the present experiment wrote the two possible written-down combinations on the problem sheets (source and/or target) without using a blackboard or left/right context. Among these, 67% successfully achieved transfer. Thus, the Blackboard THOG may facilitate correct performance and transfer through its quasi-visual context but participants need not rely solely on a blackboard representation to solve the source and target problems.

A comparison of error patterns in each problem condition also provided evidence that the Pythagoras THOG and Blackboard THOG entail features facilitating separation. Although some participants made intuitive errors in these conditions (i.e., errors that occur in response to thinking that the values of the exemplar are the values written down or the critical values for evaluating figures), significantly more did so in the Standard THOG condition, a problem with no facilitating features. These results support Newstead and Griggs's (1992; Newstead et al., 1995) "confusion theory" explanation of THOG problem performance, which proposes that the difficulty in solving the THOG problem can be reduced by facilitating separation of the values of the exemplar from the values written down. The Pythagoras THOG may have achieved this through its narrative structure, figural labeling, or hypothesis generation features. In contrast, the Blackboard THOG may have done so through educing a quasi-visual representation of the problem's underlying structure.

The similarity questionnaires revealed that participants not only observed the similarity between the source and target problems but were also using the deep structural features rather than mere surface similarity to work through the transfer problem. It should be noted that among all 75 participants (Blackboard replication excluded), only five mentioned noticing that both exemplars were black and none of these individuals correctly solved either the source or target problem. Thus, in these cases, noticing and relying on surface similarities between the source and target problems failed to elicit a correct problem solving strategy. However, because participants may still have relied on some undetected surface similarity heuristic (as suggested earlier concerning Needham & Amado's, 1995, transfer results), the contribution of surface similarity to the observed transfer effects was further explored in Experiment 2.

CHAPTER 5
EXPERIMENT 2: CHANGING THE VALUES OF THE DIMENSIONS

Introduction

The standard THOG rule references two dimensions, color and shape, and the relationship between their written down values for classifying geometric figures as THOGs or not THOGs. To investigate the contributions of surface similarity to analogical transfer, the values of these dimensions were changed. This manipulation was included to determine if analogical transfer is dependent on high surface similarity between source and target problems and if the Blackboard THOG and Pythagoras THOG problems entail sufficient deep structure features to facilitate analogical transfer in the presence of decreased surface similarity.

To answer these questions, a target problem was created that contained values different from those in the source problems. Two new shapes (cross and heart) and two new patterns (dots and stripes) replaced the shapes (circle and square) and colors (white and black) of the target THOG problems in Experiment 1 to result in a target problem labeled "Dotted Cross."

Design and Methodology

Pilot Data

Before designating the "Dotted Cross" THOG as the target problem in the experimental conditions, pilot data on this problem were collected from thirty additional participants in order to obtain a baseline measure of performance. As in the experimental conditions, participants were allotted a ten-minute problem solving time period. Correct performance on the "Dotted Cross" THOG was 20% (6/30), which is in the typical range for the abstract Standard THOG problem (0 – 29% correct, $X = 12.37$, $SD = 7.91$, averaged across 11 studies investigating performance on abstract versions of the THOG problem). The "Dotted Cross" was, therefore, designated as the target problem in this experiment. For convenience, however, results from the pilot data and the experimental data are combined.

Participants

One hundred fourteen participants were randomly assigned to the Standard THOG ($n = 38$), Blackboard THOG ($n = 38$), and Pythagoras THOG ($n = 38$) problem conditions. The increase in sample size resulted from the need to maintain sufficient statistical power in the event that decreasing surface similarity would also decrease analogical transfer.

Target Power

With an expected standard THOG percent correct of 12%, an expected transfer effect of at least 40% correct on the target problems following the Blackboard THOG and Pythagoras THOG, and a sample size of 38 per condition, target power was .70.

Procedure

The procedures for problem presentation and similarity questionnaire were the same as in Experiment 1 for the Blackboard THOG, Standard THOG, and Pythagoras THOG conditions.

Materials

All source problems were created using the same dimensions and values outlined previously in the Materials section of the Design and Methodology Overview. In the source problem, the Black Square was designated as the exemplar. In the target problem, the Dotted Cross was designated as the exemplar. In the "Dotted Cross" Standard THOG, the wording of the rule was: "A figure will be classified as a THOG if, and only if, it includes either the pattern written down or the shape written down, but not both." (see Appendix B, "Dotted Cross" Standard THOG, for exact wording.)

Transfer Problem Order Conditions

Source problem → target problem

Blackboard THOG → "Dotted Cross" Standard THOG

Pythagoras THOG → "Dotted Cross" Standard THOG

Source Standard THOG → "Dotted Cross" Standard THOG

Results

Facilitation and Transfer

The percent corrects for all problems are detailed in Table 5-1 below. Comparisons among source problems revealed that correct performance on the Source Standard THOG was significantly lower than the Pythagoras THOG, χ^2 $(1, N = 76) = 8.14$, $p = .004$, and the Blackboard THOG, χ^2 $(1, N = 76) = 6.95$, $p = .008$. Similarly, correct performance on the "Dotted Cross" Standard THOG (pilot data) was significantly lower than the Pythagoras THOG, χ^2 $(1, N = 68) = 7.56$, $p = .006$, and the Blackboard THOG, χ^2 $(1, N = 68) = 6.49$, $p = .011$.

Comparisons among target problems revealed that correct performance on the "Dotted Cross" Standard THOG was significantly better (45% correct) when it followed the Pythagoras THOG, χ^2 (1, $N = 76$) = 3.74, $p = .053$, than when it followed the Standard THOG (21% correct). However, correct performance on the "Dotted Cross" Standard THOG that followed the Blackboard THOG (37% correct) failed to achieve a statistically significant difference from the target problem following the Standard THOG, χ^2 (1, $N = 76$) = 1.56, $p = .212$.

Correct performance on the "Dotted Cross" Standard THOG (pilot data) was significantly lower than correct performance on the "Dotted Cross" Standard THOG that followed the Pythagoras THOG, χ^2 (1, $N = 68$) = 4.58, $p = .032$. Correct performance on the "Dotted Cross" Standard THOG was not, however, significantly different from correct performance on the "Dotted Cross" Standard THOG that followed the Blackboard THOG, χ^2 (1, $N = 68$) = 2.29, $p = .13$, or the "Dotted Cross" Standard THOG that followed the Standard THOG, χ^2 (1, $N = 68$) = .132, $p = .716$.

Table 5-1. Percent correct on source and target problems in Experiment 2

Problem	Source Problem	Target THOG Problem
Pythagoras THOG	53% (20/38)	45% (17/38)
Blackboard THOG	50% (19/38)	37% (14/38)
Standard THOG	21% (8/38)	21% (8/38)
"Dotted Cross" Standard THOG	20% (6/30)	n/a

Error Patterns

As in Experiment 1, the "all are THOGs" and Intuitive A errors occurred with the greatest frequency. Significantly more participants classified all figures as THOGs in the Standard THOG condition ($n = 11$) than in the Pythagoras THOG condition ($n = 1$), χ^2 (1, $N = 152$) = 9.05, $p = .003$. Intuitive A errors occurred more frequently in the Standard

THOG condition (n = 18) than in the Blackboard THOG condition (n = 7), χ^2 (1, N = 152) = 4.15, p = .042, and the Pythagoras THOG condition (n = 6), χ^2 (1, N = 152) = 5.32, p = .021. In the Standard THOG condition, the majority of the "all are THOGs" and Intuitive A errors occurred because participants made these same selections for the source and target problems. (A more detailed summary of error patterns is provided in Appendix D.)

Similarity Questionnaire

Most participants (92%), irrespective of problem performance, noticed the similarity between the source and target problems in their structure, use of dimensions and/or values, classification instructions, and/or classification rules. Sixty-eight percent of participants who successfully achieved transfer either stated or made notations indicating they had used the same strategy on both problems. This compared with 34% of those who failed to achieve transfer. (See a summary of responses in Table 5-2 below.)

Table 5-2. Responses to similarity questionnaire in Experiment 2

Response to similarity questionnaire[a]	Standard		Blackboard		Pythagoras	
	Transfer		Transfer		Transfer	
	Yes	No	Yes	No	Yes	No
Similar use of dimensions and/or values	4/8	21/30	11/14	11/24	10/18	9/20
Similar structure	4/8	5/30	7/14	2/24	3/18	3/20
Same classification rule	8/8	19/30	7/14	8/24	13/18	14/20
Same classification instructions	6/8	5/30	5/14	5/24	0/18	5/20
Similarity helped[b]	8/8	11/30	10/14	8/24	12/18	9/20
Similarity did not help[b]	0/8	8/30	1/14	7/24	0/18	4/20
Used same strategy on both problems	5/8	11/30	8/14	8/24	14/18	6/20

[a] Values in the table reflect only those participants who provided the responses summarized. Some participants provided several responses, whereas others only provided one or two.

[b] Responses as to whether or not the similarity between problems helped in solving the transfer problem were provided by only 68% of participants (range of 25 - 27 across conditions).

Notations

Participants' problem sheets were examined for additional notations beyond the circling of responses. (See Table 5-3 below for a summary of these notations.) Across all problem conditions, significantly more participants (75%, 30/40) who achieved transfer provided notations on both problem sheets than did participants who failed to achieve transfer (51%, 38/74), χ^2 (1, N = 114) = 6.03, p = .014. As in Experiment 1, the most successful participants were those who had used the same strategy on both problems.

The majority of additional notations were found on the Blackboard THOG problem sheets. In this condition, 74% (17/23) of participants who correctly solved either the Blackboard THOG, the "Dotted Cross" Standard THOG that followed the Blackboard THOG, or both, had made additional notations on at least one problem sheet that included (a) “left” or “right” labels, (b) blackboard-type drawings, and/or (c) labels of figures (e.g., white square) written in a left-right orientation on the problem sheet. This type of notation was present only once each in the Pythagoras THOG and Standard THOG conditions. In both cases, the participants had achieved analogical transfer.

In the Standard THOG condition, 43% (12/28) of completely incorrect participants (solved neither the source or target problem) made no additional notations on either problem sheet beyond the circling of responses. Sixty percent (6/10) of participants who correctly solved the Standard THOG, the "Dotted Cross" Standard THOG that followed the Standard THOG, or both, made some type of additional notation. It should be noted, however, that among those completely incorrect participants who made additional notations on at least one problem sheet, 73% (10/15) labeled the exemplar as a THOG and 20% (3/15) labeled each figure, neither or which may be particularly helpful notations.

The Pythagoras THOG elicited little additional notation beyond writing the “parents” of the THOG on its target “Dotted Cross” Standard THOG. Of those participants who correctly solved the Pythagoras THOG or achieved transfer to the "Dotted Cross" Standard THOG, 65% (15/23) and 72% (13/18), respectively, wrote the correct “parents” of the exemplar on the target problem. Only one participant who incorrectly solved the Pythagoras THOG made this notation on the target problem. It should be noted that providing the incorrect hypotheses might result in a negative transfer effect. Of those participants who failed to achieve transfer from the Pythagoras THOG to the transfer problem, 50% (10/20) had incorrectly responded to the hypothesis generation request. Only one of the 18 participants who achieved transfer produced this error.

Table 5-3. Notations on problem sheets in Experiment 2

Notations [a]	Standard		Blackboard		Pythagoras	
	Transfer		Transfer		Transfer	
	Yes	No	Yes	No	Yes	No
No notations provided	2/8	14/30	1/14	3/24	0/18	0/20
Label exemplar with "THOG" or color/shape combination on one problem only	0/8	2/30	1/14	6/24	2/18	5/20
Label exemplar with "THOG" or color/shape combination on both problems	0/8	2/30	1/14	3/24	4/18	1/20
Both correct hypotheses ("parents") provided on one problem only	0/8	8/30	6/14	9/24	4/18	7/20
Both correct hypotheses ("parents") provided on both problems	2/8	0/30	5/14	4/24	13/18	3/20
Incorrect hypotheses ("parents") provided on source problem	0/8	0/30	1/14	0/24	1/18	10/20
"Blackboard-type" drawing, left/right labels, left-right orientation of values on first problem only	1/8	0/30	9/14	14/24[b]	0/18	0/20
"Blackboard-type" drawing, left/right labels, left-right orientation of values on both problems	0/8	0/30	3/14	1/24	0/18	0/20

[a] Only notations provided at least 20% of the time in a single condition are described.

[b] Included among these values are 7 participants who correctly solved the Blackboard problem but failed to achieve transfer.

Experiment 2 Conclusions

Experiment 2 revealed the Blackboard THOG was again capable of producing facilitation. Yet, it was unable to yield statistically significant levels of analogical transfer when surface similarity in the values of the geometric figures was reduced between the source and target problem. This result suggests that participants who had demonstrated transfer with this problem in Experiment 1 may not have done so as a function of abstracting the THOG problem's underlying structure. Rather, they may have relied upon a dimensional value matching strategy. For example, the "blackboard" wording led many participants to write down the values necessary for classifying the figures (i.e., black, white, square, circle). Applying this strategy to a target problem with the exact same values may have been easier in Experiment 1. These results suggest some support for Ross's (1987) remindings theory because in the absence of high surface similarity, the Blackboard THOG produced lower levels of analogical transfer than did the Pythagoras THOG.

Support for this conclusion is derived from the notations participants provided. A comparison between Tables 4-3 and 5-3 reveals that in Experiments 1 and 2, 68% and 71% of participants, respectively, provided notations that relied on the Blackboard THOG's quasi-visual context (i.e., blackboard drawings, left/right labels, left/right orientations of values). The proportion of participants providing these notations on the source problem was greater in Experiment 2 than in Experiment 1, 61% and 48%, respectively. Yet, the proportion of participants making these notations on the target problem was less in Experiment 2 than in Experiment 1, 11% and 25%, respectively. This difference in notations on the target problem suggests some failure of transfer between the source and target problems that may have been a function of the change in dimensional values (i.e., a decrease in surface similarity).

It is also possible that the reduction in transfer for the Blackboard THOG in Experiment 2 occurred as a consequence of insufficient power. This seems less likely given that transfer effects were obtained with the Blackboard THOG when the sample size was significantly lower in Experiment 1 (i.e., 25 in Experiment 1 vs. 38 in Experiment 2). It is worth noting, however, that in Experiment 1 the level of transfer for the Standard THOG condition was 15% and in Experiment 2 increased to 21%. Thus, the combination of higher Standard THOG and lower Blackboard THOG transfer effects in Experiment 2 may have produced an underestimation of the Blackboard THOG's ability to convey the underlying structure of the THOG task. Irrespective of the correct interpretation of these results, the Blackboard THOG was dropped from further experimental investigation.

In contrast to the Blackboard THOG, the Pythagoras THOG was capable of producing both significant facilitation and analogical transfer. Evidence that 72% of participants who achieved transfer had written the “parents” of the THOG exemplar on the "Dotted Cross" Standard THOG that followed the Pythagoras THOG suggests that hypothesis generation may be an important factor in facilitating transfer. If generating these hypotheses is a "first step" in abstracting the underlying solution principle of the THOG task, the Pythagoras THOG's ability to facilitate transfer may be highly dependent upon this feature. Before exploring this possibility, one further change was introduced in Experiment 3 to extend this investigation of the contributions of surface similarity to analogical transfer.

One final issue concerning hypothesis generation is worthy of mention. Given its potential facilitating effect, it may have seemed appropriate to add hypothesis generation to the Blackboard THOG before eliminating this problem from further experimental investigation. In a preliminary investigation of the Blackboard THOG problem, Griggs and Koenig (unpublished data, 2000) found that the facilitation observed by the Blackboard THOG was not substantially improved by adding the hypothesis generation request. Correct performance on Blackboard THOGs that included a hypothesis generation request (62%) was not as high as the correct performance Koenig and Griggs (2001) obtained in both Blackboard conditions (68% and 73%), which did not include a hypothesis generation request. These results were interpreted as indicating that the hypothesis generation request added little to the facilitation the blackboard context alone was capable of yielding and would thus be unlikely to improve analogical transfer effects.

CHAPTER 6
EXPERIMENT 3: CHANGING THE DIMENSIONS

Introduction

In Experiment 2, the two dimensions (shape and pattern) in the "Dotted Cross" Standard THOG incorporated the combination of an external feature (shape) that completely enclosed an internal feature (pattern), thus maintaining surface similarity to the Standard THOG and Pythagoras THOG problems. In Experiment 3, both dimensions in the target problem were changed. The new dimensions, numbers and letters, were selected for two reasons.

First, a target problem that differed more substantially in surface features was expected to be helpful in determining the relative contributions of surface similarity and structural similarity to analogical transfer. Specifically, if transfer failed to occur, the transfer results of Experiments 1 and 2 could be partially attributed to the surface similarity between the source and target problems. In other words, the Pythagoras THOG may not have conveyed the solution principle to participants as was previously concluded. Rather, participants were likely relying on an elementary matching heuristic that was highly dependent upon surface similarity (as was proposed earlier to explain Needham & Amado's, 1995, transfer results). However, if transfer could be obtained in Experiment 3, the results would support the hypothesis that structural features within the Pythagoras problem facilitate abstraction of the solution principle that is evidenced by transfer to the target problem.

A second reason for selecting the dimensions of number and letter occurred as a consequence of searching for a problem that (a) did not contain unique facilitating features, (b) differed substantially from the source problem in its surface features and (c) maintained the underlying structure of the standard abstract THOG. Robert Cordell introduced a number of variants on the THOG problem in the (unpublished) dissertation he presented to the University of Nottingham for a Master of Education degree in 1978. Of particular interest was a letter/number problem version he described as "non-coalescing," in which he found that "no modification ha[d] any substantial facilitating effect in terms of % success rate scores" (p. 68, 1978). An earlier collection of pilot data on this problem by Griggs and Koenig (2000, unpublished data) replicated Cordell's findings. Thus, because a Letter/Number THOG problem would eliminate the internal/external surface similarity feature and because Cordell found the problem did not entail any unique facilitating features, a version of this problem was selected as the target problem for Experiment 3.

Design and Methodology

Pilot Data

Before designating the Letter/Number THOG as the target problem in the experimental conditions, pilot data were collected from thirty additional participants in order to obtain a baseline measure of performance. As in the experimental conditions, participants were allotted a ten-minute problem solving time period. Correct performance on the Letter/Number Standard THOG was 27% (8/30). This performance is at the upper level of performance typically found for abstract THOG problems but still within the range of 0 – 29% correct (*X* = 12.37, *SD* = 7.91, averaged across 11 studies investigating abstract versions of the THOG problem). Given these results and those obtained by Cordell, this problem was designated as the target problem in the experimental conditions. For convenience, however, results from the pilot data and the experimental data are combined.

Participants

Seventy-two participants were randomly assigned to the Pythagoras THOG (*n* = 36) and Standard THOG (*n* = 36) problem conditions.

Target Power

With an expected Source Standard THOG percent correct of 15%, an expected transfer effect of at least 45% correct on the target problem following the Pythagoras THOG, and a sample size of 36 per condition, target power approached .80.

Procedure

The procedures for problem presentation and similarity questionnaire were the same as in Experiments 1 and 2. Participants who worked only the Letter/Number Standard THOG (pilot data) were allotted a ten-minute problem solving time period.

Materials

All source problems were created using the same shape and color values (i.e., black, white, circle, square) as outlined previously in the Materials section of Design and Methodology Overview. In the source problem, the Black Square was designated as the exemplar. In the target problem (henceforth labeled the Letter/Number Standard THOG), the $\boxed{\text{R} \quad 8}$ was designated as the exemplar. In the Letter/Number Standard THOG problem, the wording of the rule was: "A figure will be classified as a THOG if, and only if, it includes either the letter written down or the number written down, but not both." (see Appendix B, Letter/Number Standard THOG, for exact wording.)

Transfer Problem Order Conditions

Source problem → target problem

Pythagoras THOG → Letter/Number Standard THOG

Source Standard THOG → Letter/Number Standard THOG

Results

Facilitation and Transfer

The percent corrects for all problems are detailed in Table 6-1 below. A comparison between source problems revealed that correct performance on the Pythagoras THOG was significantly higher than the Standard THOG, χ^2 (1, N = 72) = 16.37, $p < .001$. In addition, correct performance on the Letter/Number Standard THOG (pilot data) was not significantly different from the Standard THOG, χ^2 (1, N = 66) = .486, $p = .486$, but was significantly lower than correct performance on the Pythagoras THOG, χ^2 (1, N = 66) = 10.48, $p = .001$.

Table 6-1. Percent correct on source and target problems in Experiment 3

Problem	Source Problem	Target THOG Problem
Pythagoras THOG	66% (24/36)	56% (20/36)
Standard THOG	19% (7/36)	22% (8/36)
Letter/Number Standard THOG	27% (8/30)	n/a

A comparison between target problems revealed that correct performance on the Letter/Number Standard THOG was significantly better when it followed the Pythagoras THOG (56% correct) than when it followed the Standard THOG (22% correct), χ^2 (1, N = 72) = 8.42, $p = .004$. Thus, even though the pilot data revealed that correct performance on the Letter/Number Standard THOG was at the upper level typically found for the standard abstract THOG, the Pythagoras THOG contributed significantly to the transfer effects observed in this experiment.

Error Patterns

The most common error pattern in this experiment was Intuitive A, which occurred significantly more often in the Standard THOG condition (*n* = 18) than in the Pythagoras THOG condition (*n* = 6), χ^2 (1, *N* = 144) = 9.00, *p* = .003. No other errors occurred at a statistically significant higher rate in any single problem condition. (A more detailed summary of error patterns is provided in Appendix D.)

Similarity Questionnaire

Most participants (94%), irrespective of problem performance, noted the similarity between the source and target problems in their structure, dimensions and/or values, classification instructions, and/or classification rules. Sixty-one percent of participants who successfully achieved transfer either stated or made notations indicating they had used the same strategy on both problems. This compared with 16% of those who failed to achieve transfer. (See a summary of responses in Table 6-2 below.)

Notations

Participants' problem sheets were examined for any notations beyond the circling of responses. (See Table 6-3 below for a summary of these notations.) Across all problem conditions, significantly more participants (76%, 19/28) who achieved transfer provided notations on both problem sheets than did participants who failed to achieve transfer (30%, 13/44), χ^2 (1, *N* = 72) = 10.17, *p* = .001. In addition, as in Experiments 1 and 2, the most successful participants were those who had used the same strategy on both problems.

Table 6-2. Responses to similarity questionnaire in Experiment 3

Response to similarity questionnaire[a]	Standard Transfer		Pythagoras Transfer	
	Yes	No	Yes	No
Similar use of dimensions and/or values	5/8	19/28	8/20	6/16
Similar structure	1/8	7/28	6/20	3/16
Same classification rule	3/8	12/28	8/20	8/16
Same classification instructions	0/8	8/28	11/20	6/16
Similarity helped[b]	3/8	10/28	11/20	8/16
Similarity did not help[b]	1/8	7/28	2/20	5/16
Used same strategy on both problems	4/8	3/28	13/20	4/16

[a] Values in the table reflect only those participants who provided the responses summarized. Some participants provided several responses, whereas others only provided one or two.

[b] Responses concerning whether or not the similarity between problems helped in solving the transfer problem were provided by only 65% of participants (range of 21 - 26 across conditions).

In the Pythagoras THOG condition, all but one participant (97%) provided additional notations on their problem sheets. Of those participants who correctly solved the Pythagoras THOG, the Letter/Number Target THOG that followed the Pythagoras, or both the Pythagoras and Letter/Number Target THOG problems, 79% (23/27) wrote the correct "parents" of the exemplar on the source and/or target problems. Of the 12 who provided this notation on both problem sheets, 11 achieved transfer. In contrast, of the 14 who provided this notation only on the source problem sheet, four achieved transfer. These data suggest that using the hypothesis generation strategy across both problems facilitated correct performance.

In the Standard THOG condition, 41% (11/27) of completely incorrect participants (solved neither the source or target problem) made no additional notations. In contrast, 66% (6/9) of participants who correctly solved the Source, Target, or both Standard THOG problems provided additional notations. Two of the participants who achieved transfer had written the "parents" of the THOG exemplar and four demonstrated evidence of a hypothesis generation/deductive reasoning strategy. In contrast to Experiments 1 and 2, only six participants provided notations judged as unhelpful – labeling the exemplar as a THOG or labeling each figure with its values. All these participants, however, were among the group that failed to achieve analogical transfer.

Table 6-3. Notations on problem sheets in Experiment 3

Notations [a]	Standard		Pythagoras	
	Transfer		Transfer	
	Yes	No	Yes	No
No notations provided	3/8	16/28	1/20	0/16
Both correct hypotheses ("parents") provided on one problem only	2/8	1/28	5/20	10/16
Both correct hypotheses ("parents") provided on both problems	1/8	1/28	11/20	1/16
Evidence of other logical/ deductive reasoning strategy	4/8	3/28	4/20	1/16
Used same strategy on both problems	4/8	3/28	13/20	4/16

[a] Only notations provided at least 20% of the time in a single condition are described.

Experiment 3 Conclusions

The strongest test yet of analogical transfer (i.e., a significant decrease in surface similarity) revealed that the Pythagoras THOG continued to produce facilitation and analogical transfer. These results support Gick and Holyoak's (1980; 1983) and Gentner's (1983) propositions that surface similarity is not critical to facilitating analogical transfer. These findings fail, however, to support remindings theory (Ross, 1987) because a decrease in surface similarity was not accompanied by a reduction in analogical transfer. In fact, the transfer effects in the Pythagoras THOG condition were modestly higher in Experiment 3 than in Experiment 2 (56% vs. 45%, respectively).

Although performance on the Pythagoras THOG source problem was better in Experiment 3 than in Experiment 2 (66% vs. 53%, respectively) this cannot be attributed to sample differences. Participants in the Standard THOG condition performed at almost identical levels across the two experiments. In addition, correct performance on the two abstract source problems was within the typical range for the standard abstract THOG problem (0 – 29%).

If surface similarity did not contribute significantly to the analogical transfer results obtained in Experiment 3, which factor/s did? An examination of participants' problem sheets and responses to the similarity questionnaire revealed that hypothesis generation may have been of substantial importance in contributing to the obtained transfer effects. Not only did many participants use a "hypothesis generation" strategy on their target problems but also, in response to the similarity questionnaire, they conveyed the importance of this question in facilitating problem understanding.

Previously, Griggs et al. (2001) examined the contributions of two facilitating features in the Pythagoras THOG problem - narrative structure and figural labeling – separately, together, and each in combination with the hypothesis generation request. Their results indicated that a combination of any two of these factors produced substantial facilitation (> 50% correct) when compared to the Standard THOG problem. Thus, although problem sheets and similarity questionnaire responses indicated the importance of hypothesis generation, participants in the first three experiments may have also relied on these other features to facilitate abstraction of the Pythagoras THOG's underlying structure. The purpose of Experiment 4 was to investigate which combination of features would be most likely to produce both facilitation *and* analogical transfer. In doing so, a better understanding of the structural features of the Pythagoras THOG that contribute to analogical transfer would be revealed.

CHAPTER 7
EXPERIMENT 4: EXAMINING STRUCTURAL FEATURES

Introduction

Across three experiments, the Pythagoras THOG consistently revealed its ability to facilitate analogical transfer in the presence of decreasing surface similarity between source and target problems. These results clearly indicate that analogical transfer is not solely dependent on surface similarity. The issue that remains to be addressed is determining which structural features in the problem were facilitating correct performance and analogical transfer. Therefore, in Experiment 4, the three elements in the Pythagoras THOG examined previously by Griggs et al. (2001) – figural labeling, narrative structure, and hypothesis generation – were examined as possible candidates for contributing to the transfer effects in the previous experiments. Given that Griggs et al. (2001) achieved substantial facilitation (> 50% correct) with versions of the THOG problem that entailed a combination of two of these features, a similar approach was adopted in this experiment. In addition, the "Dotted Cross" Standard THOG problem was designated as the target problem. This problem was selected because a conservative approach was deemed prudent. If too many changes were introduced (i.e., structural changes to the Pythagoras THOG *and* changes in both the dimensions and values), it may have been difficult to evaluate which factors contributed to either successful or failed transfer effects.

Design and Methodology

Participants

One hundred twenty participants were randomly assigned to either the Standard THOG, Narrative + Label THOG, Narrative + Hypothesis Generation THOG, or Label + Hypothesis Generation THOG problem conditions. Given that baseline pilot data had previously been collected on the "Dotted Cross" Standard THOG problem, no participants were assigned to work this problem alone.

Target Power

With an expected Source Standard THOG percent correct of 15% (based on combining this dissertation's data from Experiments 1, 2, and 3 with previous Standard THOG performance rates), an expected transfer effect of at least 45% correct on the target problem following the various versions of the Pythagoras problem, and a sample size of 30 per condition, target power was .70.

Materials

The Pythagoras THOG problem was modified to create three source problems that incorporated the same shape and color values (i.e., black, white, circle, square) of the source problems used in the three preceding experiments. In the Narrative + Label THOG, the hypothesis generation request was removed (i.e., participants were not asked to determine which features Professor Pythagoras might have written on a card that resulted in the Black Square being labeled as a THOG). In the Label + Hypothesis Generation THOG, the narrative was removed (i.e., the Professor Pythagoras story was replaced with the standard abstract THOG wording). In the Narrative + Hypothesis Generation THOG, the figural labeling was removed (i.e., the figures were presented without any labels). (See Appendix B for examples of these three problems.) As mentioned earlier, the "Dotted Cross" Standard THOG developed for Experiment 2 was designated as the target problem.

Transfer Problem Order Conditions

Source problem → target problem

Narrative + Label THOG → "Dotted Cross" Standard THOG

Narrative + Hypothesis Generation THOG → "Dotted Cross" Standard THOG

Label + Hypothesis Generation THOG → "Dotted Cross" Standard THOG

Source Standard THOG → "Dotted Cross" Standard THOG

Results

Facilitation and Transfer

The percent corrects for all source and target problems are detailed in Table 7-1 below. Comparisons among source problems revealed that correct performance on the Source Standard THOG (17%) was significantly lower than the Narrative + Label THOG (47%), χ^2 (1, N = 60) = 6.24, p = .012, the Narrative + Hypothesis Generation THOG (57%), χ^2 (1, N = 60) = 10.34, p = .001, and the Label + Hypothesis Generation THOG (73%), χ^2 (1, N = 60) = 19.46, $p < .001$. In addition, correct performance was significantly better in the Label + Hypothesis Generation THOG condition than in the Narrative + Label THOG condition, χ^2 (1, N = 60) = 4.44, p = .035.

A comparison among target problems revealed that performance on the "Dotted Cross" Standard THOG was significantly better when it followed the Label + Hypothesis Generation THOG, χ^2 (1, N = 60) = 8.15, p = .004, and the Narrative + Hypothesis Generation THOG, χ^2 (1, N = 60) = 5.55, p = .018, than when it followed the Source

Standard THOG. However, correct performance on the "Dotted Cross" Standard THOG that followed the Narrative + Label THOG was not significantly different from the "Dotted Cross" Standard THOG that followed the Source Standard THOG problem, χ^2 $(1, N = 60) = 2.58, p = .108$.

Table 7-1. Percent correct on source and target problems in Experiment 4

Problem	Source Problem	Target THOG Problem
Narrative + Label	14/30 (47%)	14/30 (47%)
Narrative + Hypothesis Generation	17/30 (57%)	17/30 (57%)
Label + Hypothesis Generation	22/30 (73%)	19/30 (63%)
Standard THOG	5/30 (17%)	8/30 (27%)

Error Patterns

The most common error patterns in this experiment were Intuitive A and Intuitive B, none of which occurred significantly more often in any single problem condition. However, the frequency of Type A errors approached a statistically significant level when a comparison was made between the Standard THOG condition ($n = 12$) and the Label + Hypothesis Generation THOG condition ($n = 5$), χ^2 $(1, N = 60) = 3.36, p = .067$. (A more detailed summary of error patterns is provided in Appendix D.)

Similarity Questionnaire

Most participants (93%), irrespective of problem performance, noted the similarity between the source and target problem in their structure, use of dimensions and/or values, classification instructions, and/or classification rules. Sixty-seven percent of participants who successfully achieved transfer either stated or made notations indicating they had used the same strategy on both problems. This compared with 18% of those who failed to achieve transfer. (See a summary of responses in Table 7-2 below.)

Table 7-2. Responses to similarity questionnaire in Experiment 4

Response to similarity questionnaire [a]	Standard		Narrative + Label		Narrative + Hyp Gen		Label + Hyp Gen	
	Transfer		Transfer		Transfer		Transfer	
	Yes	No	Yes	No	Yes	No	Yes	No
Similar use of values and/or dimensions	5/8	16/22	4/14	6/16	8/17	5/13	9/19	4/11
Similar structure	1/8	7/22	1/14	4/16	0/17	4/13	3/19	3/11
Same classification rule	7/8	9/22	10/14	9/22	8/17	6/13	13/19	5/11
Same classification instructions	3/8	10/22	7/14	6/16	7/17	3/13	6/19	1/11
Similarity helped [b]	3/8	7/22	8/14	9/16	10/17	3/13	12/19	3/11
Similarity did not help [b]	1/8	5/22	0/14	3/16	0/17	4/13	2/19	1/11
Used same strategy on both problems	5/8	4/22	11/14	2/16	11/17	4/13	12/19	1/11

[a] Values in the table reflect only those participants who provided the responses summarized. Some participants provided several responses, whereas others only provided one or two.

[b] Responses concerning whether or not the similarity between problems helped in solving the transfer problem were provided by only 65% of participants (range of 21 - 26 across conditions).

Notations

Participants' problem sheets were examined for any notations beyond the circling of responses. (See Table 7-3 below for a summary of these notations.) The presence of notations was lowest in the Standard THOG (67%) and Narrative + Label THOG (73%) conditions. In contrast, all participants in the Narrative + Hypothesis Generation THOG and 97% in the Label + Hypothesis Generation THOG conditions made some type of additional notation on either one or both problem sheets. Across all problem conditions, significantly more participants (78%, 45/58) who achieved transfer provided notations on both problem sheets than did participants who failed to achieve transfer (45%, 28/62), χ^2 $(1, N = 120) = 13.22, p < .001$. In addition, the most successful participants were those who used the same strategy on both problems.

The most frequent notation across all source and target problems was writing the "parents" of the exemplar (i.e., hypothesis generation). Among those participants who wrote the correct "parents" on both problem sheets, 94% (30/32) achieved analogical transfer. The majority of these notations occurred on the problems that included a hypothesis generation request ($n = 21$). However, eight participants in the Label + Narrative THOG condition and one in the Standard THOG condition also included this notation despite the absence of specific instructions to generate hypotheses.

Table 7-3. Notations on problem sheets in Experiment 4

Notations[a]	Standard		Narrative + Label		Narrative + Hyp Gen		Label + Hyp Gen	
	Transfer		Transfer		Transfer		Transfer	
	Yes	No	Yes	No	Yes	No	Yes	No
No notations provided	0/8	10/22	3/14	5/16	0/17	0/13	1/19	0/11
Both correct hypotheses (“parents”) provided on one problem only	2/8	2/22	0/14	5/16	4/17	8/13	3/19	5/11
Both correct hypotheses (“parents”) provided on both problems	1/8	0/22	8/14	0/16	10/17	2/13	11/19	0/11
Evidence of other logical/deductive reasoning strategy	3/8	2/22	5/14	3/16	0/17	1/13	2/19	0/11
Incorrect hypotheses (“parents”) provided on either problem	0/8	0/22	1/14	0/16	1/17	0/13	0/19	1/11
Label exemplar with “THOG” or color/shape combination on one/both problems	2/8	4/22	2/14	5/16	6/17	1/13	3/19	1/11
Used same strategy on both problems	5/8	8/22	11/14	4/16	12/17	4/13	12/19	1/11

[a] Values in the table reflect only those participants who provided the responses summarized. Some participants provided several responses, whereas others only provided one or two.

Experiment 4 Conclusions

The results of Experiment 4 demonstrated that the Pythagoras THOG contains unique structural features that facilitate abstraction of the THOG task's underlying structure and contribute differentially to analogical transfer. Specifically, when either figural labeling or narrative structure was combined with a hypothesis generation request, significant analogical transfer was obtained. However, when figural labeling was combined with narrative structure and no hypothesis generation request was included, significant analogical transfer failed to occur.

Although Griggs et al. (2001) obtained substantial facilitation with versions of the Pythagoras THOG containing *any two* of the facilitating factors, Experiment 4 revealed that hypothesis generation was an *essential* structural feature for transferring the THOG problem's solution principle to a target problem. This result was not completely surprising given that one of the most frequent notations in Experiment 4 was providing the "parents" (i.e., the hypotheses) of the exemplar on both the source and target problems. In addition, many participants mentioned the importance of applying the hypothesis generation strategy when solving the target problem.

Prior to the present research, it has been widely acknowledged that hypothesis generation alone fails to contribute to significant facilitation on either thematic or abstract THOG problems (Girotto & Legrenzi, 1993; Newstead & Griggs, 1992; Smyth & Clark, 1986; Wason & Brooks, 1979). Rather, versions that facilitate separation of the hypothesized written-down combinations from the given exemplar appear to be more beneficial. The correct performance levels on the three source problem versions of the Pythagoras THOG in Experiment 4 support previous assertions that hypothesis generation *is not* necessary for producing facilitation (Koenig & Griggs, 2001; Needham & Amado, 1995). It was clear, however, that this feature *is* necessary for eliciting analogical transfer. The reason for this difference may be that the cognitive tasks required for solving the THOG problem are quite different from those needed to transfer the solution principle to another problem. This potential explanation will be elaborated more fully in the Summary.

CHAPTER 8
SUMMARY

This research used a modification of the analogical transfer experimental paradigm to investigate the contributions of surface and structural similarity to hypothetico-deductive reasoning in the THOG task. In most investigations of analogical transfer, participants are provided the solution principle and the primary goal is to determine which factors produce analogical transfer. In the present study, participants were required to both "discover" the solution principle and then to transfer this knowledge to a target problem. Typically in studies of hypothetico-deductive reasoning, correct performance has been the criterion for judging problem comprehension and emphasis has been on factors that facilitate correct performance. In contrast, the criterion for problem understanding in this research was correct performance on target problems with an emphasis on the factors that facilitate analogical transfer. The underlying assumption was that in order to transfer the solution principle to a target problem, participants had to abstract it from the source problem.

Surface and Structural Similarity

The first issue this research addressed was the relative contribution of surface similarity to analogical transfer. Among researchers investigating analogical transfer, the individual and combined influences of surface and structural similarity have been of important theoretical interest (Reeves & Weisberg, 1994). There is little argument concerning the importance of structural similarity – without it the concept of "analogical transfer" is immaterial. Most theoretical disagreements center on the role that surface similarity plays in facilitating analogical transfer.

The first three experiments in the present study revealed more support for structural similarity as a mechanism for facilitating analogical transfer. This does not mean that surface similarity played no role in increasing the likelihood of analogical transfer. Across all experiments, it was evident that participants noticed the surface similarities between source and target problems. A substantial majority (89 – 93%) mentioned similarities in the use of dimensions and/or values, the wording of the classification rule, the classification instruction, and/or the general structure/reasoning of each problem. However, noticing these surface similarities *did not* differentiate between the participants who did or did not achieve analogical transfer. In contrast, the most successful participants were those who applied the same successful strategy (i.e., the solution principle) across both problems. In most cases, this involved writing down the "parents" (i.e., a hypothesis generation strategy) of the exemplar on both problem sheets.

Separation and Hypothesis Generation

The finding in Experiment 2 that participants in the Blackboard THOG condition failed to obtain significant analogical transfer when surface similarity was modestly decreased was initially interpreted as indicating that participants in Experiment 1 may have relied more on surface features to facilitate their transfer effects. Following Experiment 4, it became apparent that decreased surface similarity combined with absence of a hypothesis generation request might have been responsible for the failed transfer effects in Experiment 2.

It is evident the Blackboard THOG contains features that achieve separation of the exemplar from the possible written-down combinations. Previous research on this problem (Koenig & Griggs, 2001) and the results of Experiments 1 and 2 of the present study clearly demonstrated these *facilitating* effects. However, facilitation and analogical transfer must require abstracting different aspects of the THOG problem's underlying structure because evidence of the former did not guarantee the latter.

Much of the recent research on the THOG task has emphasized separation as an important mechanism for facilitating correct performance (e.g., Griggs et al., 2001; Needham & Amado, 1995). The Pythagoras THOG appears to achieve this through its narrative structure and labeling features. The Blackboard THOG achieves separation through the quasi-visual context of a blackboard. Interestingly, though, the unique facilitating features in each of these problems were not sufficient to reliably produce analogical transfer (especially when surface similarity was reduced). Yet, when hypothesis generation was added to either the labeling or narrative structure features of the Pythagoras THOG, analogical transfer did occur.

Facilitating Analogical Transfer

An examination of "confusion theory" (Newstead et al., 1995; Newstead & Griggs, 1992) helps to explicate these results. According to confusion theory, the combined tasks of generating hypotheses, holding them in memory, and simultaneously testing them surpass working memory limitations. The response to this confusion is to simplify the THOG task by incorrectly assuming that the values of the exemplar are the values that have been written down. This simplification strategy has been cited as the predominant cause of Type A and Type B intuitive errors (Newstead & Griggs, 1992). In the present study, there was substantial evidence that the frequency of intuitive errors was significantly lower in the Blackboard THOG and Pythagoras THOG problem conditions, lending support to their abilities to facilitate separation.

One mechanism for reducing confusion and working memory load in the present study was to allow and encourage participants to work through the problems by writing on their problem sheets. Across all experiments, it was evident that those participants who provided notations on *both* problems – especially those who wrote the "parents" of the exemplar – were those who were most likely to achieve analogical transfer. By writing these down, participants were released from holding in memory at least one element of the solution principle. Clearly, this was a successful strategy because in all but one condition in Experiment 4, which only approached significance (i.e., Label + Hypothesis Generation THOG vs. Standard THOG), Intuitive A errors occurred significantly more often in the Standard THOG conditions, suggesting that in the other problem conditions confusion was being reduced by separation.

The importance of hypothesis generation for facilitating analogical transfer was surprising given the well-replicated finding that hypothesis generation alone typically has not lead to facilitation (Girotto & Legrenzi, 1989; Griggs, Platt, Newstead, & Jackson, 1998; Smyth & Clark, 1986; Wason & Brooks, 1979). How is it possible to reconcile these competing results? The answer lies in the *combination* of features required to produce analogical transfer.

According to Reeves and Weisberg (1994), the solution principle of a problem should be encoded in order for analogical transfer to occur. The results across the present four experiments demonstrated that participants needed to be able to (a) *separate* the exemplar from the possible combinations written down and (b) *encode* the "first step" of the THOG problem's solution principle – generating hypotheses for the two possible written-down combinations. The significantly high proportion of successful participants who utilized the hypothesis generation strategy for solving both problems provided evidence that encoding this element contributed significantly to analogical transfer. In addition, it was only when some separating feature was combined with hypothesis generation that analogical transfer occurred.

One of the most important findings in the present study replicates what is typically found in studies of analogical transfer – that it is almost impossible to obtain transfer without some type of experimental help. Although in the present study the "help" was *indirect* (i.e., no training, instructions, or hints were provided), Experiment 4 clarified that the hypothesis generation request appeared to act as an "instruction" by providing participants with the first necessary step toward solving the Standard THOG target problems. It seems that providing this request in the Pythagoras THOG prompted participants, upon noticing the similarities between the two problems, to apply this strategy to the target problem and then go on to use the remainder of the solution principle.

Reconsidering the THOG Task

The past twenty years of research on the THOG task have resulted in three empirically supported conclusions. First, it has been suggested that the majority of individuals are incapable of understanding the *abstract* THOG task. Second, separation of the exemplar from the hypothetically written down combinations has been proposed as the primary means of improving solution rates. Finally, correct performance on the

THOG task has been cited as evidence of mature hypothetico-deductive reasoning. The results of the present four experiments suggest a reconsideration of these conclusions.

First, in combination with two recent papers on the Blackboard THOG and Pythagoras THOG (Griggs et al., 2001; Koenig & Griggs, 2001), the present results indicate that from 44% to 73% of individuals *are capable* of reasoning hypothetically and deductively on abstract versions of the THOG task. This is substantially higher than has previously been observed among abstract problems that are structurally isomorphic to the standard abstract THOG task. Thus, the present study contributes to a growing body of evidence that the majority of adult individuals *are* capable of understanding and reasoning correctly about this task if they can be led to abstract its underlying solution principle. Second, although recent versions of the THOG task have improved correct performance through facilitating separation, this may not necessarily indicate a true understanding of the steps necessary for solving the task. The present research demonstrated that, in the absence of high surface similarity, it was necessary to provide participants with the "first step" of the THOG task in order to facilitate transfer of a problem solving strategy from one problem to another.

An earlier investigation of the THOG task by Griggs and Newstead (1982) revealed a lack of transfer to the abstract THOG (as was found with the Blackboard THOG of the present Experiment 2) despite significantly high levels of correct performance on the source problems. As they stated, "…it seems the major difficulty of the THOG problem is one of constructing an adequate representation. If the problem is presented in a way that makes the problem structure very clear, then subjects seem quite capable of carrying out the requisite combinatorial analysis" (pp. 306-307, 1982). In the present study, it was evident that separation helped participants construct what Griggs and Newstead called an "adequate representation" of the task. However, an "adequate representation" may not indicate complete understanding because separation alone did not appear to facilitate analogical transfer, especially when surface similarity was reduced (i.e., the non-significant Blackboard THOG transfer results in Experiment 2).

Finally, the importance of using analogical transfer rather than facilitation as the criterion for judging problem comprehension needs to be considered. Historically, investigators of the THOG task have primarily emphasized facilitation because correct performance has typically been very poor. Only recently (Griggs et al., 2001; Koenig & Griggs, 2001; Needham & Amado, 1995) have versions of the THOG problem been developed or tested that have led to reliably higher levels of correct performance – ranging from 68% to 73%. As a consequence, researchers have begun to reevaluate the commonly held assumption that the THOG task is beyond the reasoning and problem solving capabilities of most research participants. In the presence of such high levels of correct performance, it has been suggested that the *majority* of participants *are* capable of reasoning hypothetically and deductively on the THOG task if the underlying structure is made more evident (Griggs et al., 2001; Koenig & Griggs, 2001). The purpose of this investigation was to examine this suggestion by using analogical transfer as a stronger test of problem comprehension.

This study has been one of the first to reveal that adult participants are capable of both solving *and* transferring the solution principle of a structurally isomorphic THOG problem to a significantly more difficult abstract THOG task. The necessity of the hypothesis generation request revealed that, as in most analogical transfer experiments, participants required some type of experimental "help," albeit indirect, before applying the abstracted solution principle to a target task that differed in its surface features. Prior evidence that separation alone facilitated problem comprehension needs to be qualified by evidence that true understanding of the THOG task appeared to only emerge when participants also understood the necessity of generating and testing hypotheses. Thus, after more than twenty years of research on the THOG task, it is evident that participants do not “spontaneously” utilize the formal operational thought Piaget (1972) proposed all mature adults are capable of exhibiting. Rather, they must be “trained” to detect and use the “common stimulus-response elements” among problems that Thorndike (1906) believed were responsible for most transfer of learning effects.

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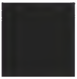
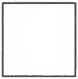
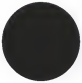
APPENDIX A
STANDARD THOG PROBLEM

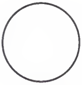
Below are four figures. Each figure is either black or white and square or circle. By writing down one of these colors (either black or white) and one of these shapes (either square or circle), I have developed a classification rule for the four figures.

The rule is: “A figure will be classified as a THOG if and only if it includes EITHER the color written down, OR the shape written down, BUT NOT BOTH.”









I will tell you that the Black Square is a THOG.

Using this piece of information and the classification rule given above, decide for each of the other figures whether or not it can be classified as a THOG.

For each figure, circle your choice:

White Square	IS a THOG	IS NOT a THOG	Can’t tell
Black Circle	IS a THOG	IS NOT a THOG	Can’t tell
White Circle	IS a THOG	IS NOT a THOG	Can’t tell

APPENDIX B
VARIANTS OF THE THOG PROBLEM

Pythagoras THOG

Professor Pythagoras is a mathematician who works in the area of geometry. He is always coming up with various schemes for classifying different geometric figures. He works on both strange figures and simple ones. He leaves part of the job of classifying simple figures to his assistant.

For a while now, the professor has been working on schemes that classify various figures as to whether they are THOGs or not, depending on the color (black or white) and the shape (square or circle) of the figure. Each time the professor comes up with a new scheme, he gives his assistant an index card with information about the scheme, and the assistant tapes the card to the wall over his desk. On the card, the professor writes two things: first, the name of one of the colors (either "black" or "white"), second, the name of one of the shapes (either "square" or "circle").

Below that card on the wall over the assistant's desk is posted the professor's permanent classification rule: "**A figure will be classified as a THOG if and only if EITHER its color matches the color name on the card above, OR its shape matches the shape name on the card above, BUT NOT BOTH. If it matches BOTH the color and the shape names or NEITHER the color or shape name, then it is not a THOG.**

On a certain day, the professor has given the assistant a new card to tape up, and the assistant is considering four figures he has on his desk.

The figures are:

Figure 1

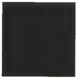


Figure 2

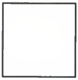


Figure 3

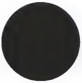
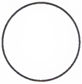


Figure 4



The assistant correctly classifies Figure 1 as being a THOG.

1) Given this piece of information about Figure 1, write down each of the possible things (each in the form: color, shape) which Professor Pythagoras MIGHT have written on the new card that would produce that result.

2) Using your answer to (1) and the classification rule given above, decide for each of the other figures, whether or not it can be classified as a THOG.

For each figure, circle your choice:

Figure 2	IS a THOG	IS NOT a THOG	Can't tell
Figure 3	IS a THOG	IS NOT a THOG	Can't tell
Figure 4	IS a THOG	IS NOT a THOG	Can't tell

Narrative THOG

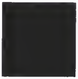
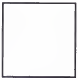
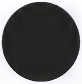
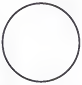
Professor Pythagoras is a mathematician who works in the area of geometry. He is always coming up with various schemes for classifying different geometric figures. He works on both strange figures and simple ones. He leaves part of the job of classifying simple figures to his assistant.

For a while now, the professor has been working on schemes that classify various figures as to whether they are THOGs or not, depending on the color (black or white) and the shape (circle or square) of the figure. Each time the professor comes up with a new scheme, he gives his assistant an index card with information about the scheme, and the assistant tapes the card to the wall over his desk. On the card, the professor writes two things: first, one of the colors (either "black" or "white"), second, one of the shapes (either "circle" or "square").

Below that card on the wall over the assistant's desk is posted the professor's permanent Classification Rule: **"A figure will be classified as a THOG if and only if EITHER its color matches the color on the card above, OR its shape matches the shape on the card above, BUT NOT BOTH. If it matches BOTH the color and the shape or NEITHER the color or shape, then it is not a THOG."**

On a certain day, the professor has given the assistant a new card to tape up, and the assistant is considering four figures he has on his desk.

The figures are:

The assistant correctly classifies the black square as being a THOG.

Using this piece of information and the Classification Rule given above, decide for each of the other figures, whether or not it can be classified as a THOG.

For each figure, circle your choice:

White Square	IS a THOG	IS NOT a THOG	Can't tell
Black Circle	IS a THOG	IS NOT a THOG	Can't tell
White Circle	IS a THOG	IS NOT a THOG	Can't tell

Label THOG

Below are four figures. Each figure is either black or white and square or circle. By writing down one of these color names and one of these shape names, I have developed a classification rule for the four figures.

The rule is: **"A figure will be classified as a THOG if and only if EITHER its color matches the color name written down, OR its shape matches the shape name written down, BUT NOT BOTH. If it matches BOTH the color and shape names written down or NEITHER the color or shape name written down, then it is not a THOG."** The figures are:

Figure 1

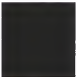


Figure 2

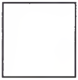


Figure 3

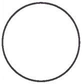
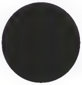


Figure 4



I can tell you that Figure 1 is a THOG.

Using this piece of information and the classification rule given above, decide for each of the other figures, whether or not it can be classified as a THOG.

For each figure, circle your choice:

Figure 2	IS a THOG	IS NOT a THOG	Can't tell
Figure 3	IS a THOG	IS NOT a THOG	Can't tell
Figure 4	IS a THOG	IS NOT a THOG	Can't tell

Narrative + Label THOG

Professor Pythagoras is a mathematician who works in the area of geometry. He is always coming up with various schemes for classifying different geometric figures. He works on both strange figures and simple ones. He leaves part of the job of classifying simple figures to his assistant.

For a while now, the professor has been working on schemes that classify various figures as to whether they are THOGs or not, depending on the color (black or white) and the shape (square or circle) of the figure. Each time the professor comes up with a new scheme, he gives his assistant an index card with information about the scheme, and the assistant tapes the card to the wall over his desk. On the card, the professor writes two things: first, the name of one of the colors (either "black" or "white"), second, the name of one of the shapes (either "square" or "circle").

Below that card on the wall over the assistant's desk is posted the professor's permanent classification rule: "**A figure will be classified as a THOG if and only if EITHER its color matches the color name on the card above, OR its shape matches the shape name on the card above, BUT NOT BOTH. If it matches BOTH the color and the shape names or NEITHER the color or shape name, then it is not a THOG."**

On a certain day, the professor has given the assistant a new card to tape up, and the assistant is considering four figures he has on his desk.

The figures are:

Figure 1

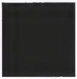


Figure 2

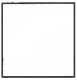


Figure 3

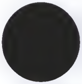
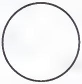


Figure 4



The assistant correctly classifies Figure 1 as being a THOG.

Using this piece of information and the classification rule given above, decide for each of the other figures, whether or not it can be classified as a THOG.

For each figure, circle your choice:

Figure 2	IS a THOG	IS NOT a THOG	Can't tell
Figure 3	IS a THOG	IS NOT a THOG	Can't tell
Figure 4	IS a THOG	IS NOT a THOG	Can't tell

Narrative + Hypothesis Generation THOG

Professor Pythagoras is a mathematician who works in the area of geometry. He is always coming up with various schemes for classifying different geometric figures. He works on both strange figures and simple ones. He leaves part of the job of classifying simple figures to his assistant.

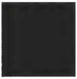
For a while now, the professor has been working on schemes that classify various figures as to whether they are THOGs or not, depending on the color (black or white) and the shape (circle or square) of the figure. Each time the professor comes up with a new scheme, he gives his assistant an index card with information about the scheme, and the assistant tapes the card to the wall over his desk. On the card, the professor writes two things: first, one of the colors (either "black" or "white"), second, one of the shapes (either "circle" or "square").

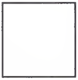
Below that card on the wall over the assistant's desk is posted the professor's permanent Classification Rule: "**A figure will be classified as a THOG if and only if EITHER its color matches the color on the card above, OR its shape matches the shape on the**

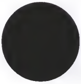
card above, BUT NOT BOTH. If it matches BOTH the color and the shape or NEITHER the color or shape, then it is not a THOG."

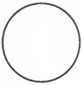
On a certain day, the professor has given the assistant a new card to tape up, and the assistant is considering four figures he has on his desk.

The figures are:









The assistant correctly classifies the black square as being a THOG.

1) Given this piece of information about the black square, write down each of the possible things (each in the form: color, shape) which Professor Pythagoras MIGHT have written on the new card that would produce that result.
2) Using your answer to (1) and the Classification Rule given above, decide for each of the other figures, whether or not it can be classified as a THOG.

For each figure, circle your choice:

White Square	IS a THOG	IS NOT a THOG	Can't tell
Black Circle	IS a THOG	IS NOT a THOG	Can't tell
White Circle	IS a THOG	IS NOT a THOG	Can't tell

Label + Hypothesis Generation THOG

Below are four figures. Each figure is either black or white and circle or square. By writing down one of these color names and one of these shape names, I have developed a classification rule for the four figures.

The rule is: "**A figure will be classified as a THOG if and only if EITHER its color matches the color name written down, OR its shape matches the shape name written down, BUT NOT BOTH. If it matches BOTH the color and shape names written down or NEITHER the color or shape names written down, then it is not a THOG.**"

The figures are:

Figure 1

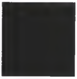


Figure 2

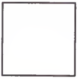


Figure 3

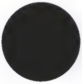
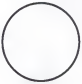


Figure 4



I can tell you that Figure 1 is a THOG.

1) Given this piece of information about Figure 1, write down each of the possible things (each in the form: color, shape) which I MIGHT have written down that would produce that result.

2) Using your answer to (1) and the Classification Rule given above, decide for each of the other figures, whether or not it can be classified as a THOG.

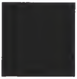
For each figure, circle your choice:

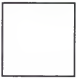
Figure 2	IS a THOG	IS NOT a THOG	Can't tell
Figure 3	IS a THOG	IS NOT a THOG	Can't tell
Figure 4	IS a THOG	IS NOT a THOG	Can't tell

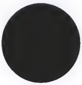
Blackboard THOG

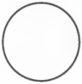
Below are four figures. Each figure is either black or white and square or circle. On the left-hand side of a blackboard I have written down one of the colors (either black or white) and one of the shapes (either square or circle). On the right-hand side of the blackboard I have written down the other color and the other shape.

If, and only if, a figure includes either the color written down on the left-hand side of the blackboard or the shape written down on the left-hand side of the blackboard, but not both, then it is called a THOG.









I will tell you that the Black Square is a THOG.

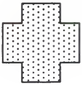
Given this piece of information about the Black Square and the classification rule given above, decide for each of the other figures whether or not it can be classified as a THOG.

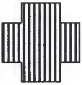
For each figure, circle your choice.

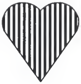
White Square	IS a THOG	IS NOT a THOG	Can't tell
Black Circle	IS a THOG	IS NOT a THOG	Can't tell
White Circle	IS a THOG	IS NOT a THOG	Can't tell

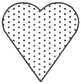
"Dotted Cross" Standard THOG

Below are four figures. Each figure is either dotted or striped and cross or heart. By writing down one of these patterns (either dotted or striped) and one of these shapes (either cross or heart), I have developed a classification rule for the four figures.
The rule is: **"A figure will be classified as a THOG if and only if it includes EITHER the pattern written down, OR the shape written down, BUT NOT BOTH."**









I will tell you that the Dotted Cross is a THOG.

Using this piece of information and the classification rule given above, decide for each of the other figures whether or not it can be classified as a THOG.

For each figure, circle your choice:

Striped Cross	IS a THOG	IS NOT a THOG	Can't tell
Striped Heart	IS a THOG	IS NOT a THOG	Can't tell
Dotted Heart	IS a THOG	IS NOT a THOG	Can't tell

Letter/Number Standard THOG

Below are four cards. Each card includes either an R or T and a 6 or 8. By writing down one of these letters (either R or T) and one of these numbers (either 6 or 8), I have developed a classification rule for the four cards.

The rule is: **"A card will be classified as a THOG if and only if it includes EITHER the letter written down, OR the number written down, BUT NOT BOTH."**

R 8	**T 6**	**T 8**	**R 6**

I will tell you that **R 8** **is a THOG.**

Using this piece of information and the classification rule given above, decide for each of the other cards whether or not it can be classified as a THOG.

For each card, circle your choice:

T 6	IS a THOG	IS NOT a THOG	Can't Tell
T 8	IS a THOG	IS NOT a THOG	Can't Tell
R 6	IS a THOG	IS NOT a THOG	Can't Tell

APPENDIX C
ADDITIONAL EXPERIMENTAL MATERIALS

Oral Instructions for Transfer Conditions

The purpose of the experiment that you are participating in today is to investigate how people solve deductive reasoning problems. This experiment will take no more than 30 minutes, so you will receive 1 credit toward your experimental requirement in General Psychology. Please read and sign the informed consent found on your desk. I will collect it as I hand out the first problem.

I will begin by giving you a sheet of paper upon which you will find one deductive reasoning problem and the instructions for the problem. What I am most interested in is your best performance, so you will be given 10 minutes to complete it. I will announce when ten minutes have passed and then collect the problem. I will then give you a second deductive reasoning problem. Again, you will be given 10 minutes to complete the problem. Please do not leave when you have finished the second problem. I will collect these problems when the second 10 minute time period has passed.

Both of these problems require logical reasoning and they both have correct answers. The problems are not as simple as they may seem at first so please use each ten minute time period to work toward the correct solution of each problem. Feel free to use the problem sheet to write on as you work through each problem. Please do not discuss this experiment with other students enrolled in General Psychology because it could affect their performance if they also participate in this experiment. Please work quietly, without talking to other students. As you leave, please take a copy of this debriefing statement and a copy of the informed consent (if you wish).

Are there any questions before I begin? (Distribute problems)

As I collect the second problem I will be providing you with a brief questionnaire. Please use the remaining time in this experiment to respond to this questionnaire. I will announce when the time is up and you may then turn in the questionnaire as you leave.

Oral Instructions for Single Problem Conditions

The purpose of the experiment that you are participating in today is to investigate how people solve deductive reasoning problems. This experiment will take no more than 30 minutes, so you will receive 1 credit toward your experimental requirement in General Psychology. Please read and sign the informed consent found on your desk. I will collect it as I hand out the problem.

I will begin by giving you a sheet of paper upon which you will find one deductive reasoning problem and the instructions for the problem. What I am most interested in is your best performance, so you will be given 10 minutes to complete it. Please do not leave when you have finished this problem. I will collect this problem when the ten-minute time period has passed.

This problem requires logical reasoning and it does have a correct answer. The problem is not as simple as it may seem at first so please use the ten-minute time period to work toward the correct solution of the problem. Feel free to use the problem sheet to write on as you work through the problem.

Please do not discuss this experiment with other students enrolled in General Psychology because it could affect their performance if they also participate in this experiment.

Please work quietly, without talking to other students. As you leave, please take a copy of this debriefing statement and a copy of the informed consent (if you wish).

Are there any questions before I begin?

Informed Consent – Transfer Conditions

This experiment is designed to investigate how people solve deductive reasoning problems. You will be asked to solve two deductive reasoning problems. You will be given a piece of paper providing instructions for the first problem and the problem itself. You will be asked to read the instructions then attempt to solve the problem. After ten minutes, the first problem will be collected and you will be given a second problem to solve. You will have ten minutes to work on this second problem. Each problem requires logical reasoning, and does have a correct answer. I am interested in your best performance, so please take your time and do not rush to make a judgment.

The experiment will take no more than 30 minutes. For your participation, you will receive 1 credit toward your experimental requirement in General Psychology. There are no other benefits or known risks related to your participation in this study. You do not have to answer any question you do not wish to answer. You may withdraw at any time without consequence. To protect your privacy, you will be assigned a subject number. Neither your name nor bar code will be recorded with your data.

My name is Cynthia Koenig, the principal investigator of this research, and this experiment is being conducted under the supervision of Dr. Richard Griggs at the University of Florida. If you have any questions, you may leave a message for me at 392-0605, ext. 483. My office is in Room 38 in the Psychology Building.

If you have any questions or concerns about your rights as a research participant, please direct your inquiries to the UFIRB office, P. O. Box 112250, University of Florida, Gainesville, FL 32611-2250; phone 392-0433.

If you wish to participate in this experiment, please sign and date a copy of this Informed Consent below and return it to the experimenter. This will indicate your voluntary willingness to participate. If you prefer not to participate, you may leave.

Informed Consent – Single Problem Conditions

This experiment is designed to investigate how people solve a deductive reasoning problem. You will be asked to solve one deductive reasoning problem. You will be given a piece of paper providing instructions for the problem and the problem itself. You will be asked to read the instructions then attempt to solve the problem. The problem requires logical reasoning, and does have a correct answer. I am interested in your best performance, so please take your time and do not rush to make a judgment.

The experiment will take no more than 30 minutes. For your participation, you will receive 1 credit toward your experimental requirement in General Psychology. There are no other benefits or known risks related to your participation in this study. You do not have to answer any question you do not wish to answer. You may withdraw at any time without consequence. To protect your privacy, you will be assigned a subject number. Neither your name nor bar code will be recorded with your data.

My name is Cynthia Koenig, the principal investigator of this research, and this experiment is being conducted under the supervision of Dr. Richard Griggs at the University of Florida. If you have any questions, you may leave a message for me at 392-0605, ext. 483. My office is in Room 38 in the Psychology Building.

If you have any questions or concerns about your rights as a research participant, please direct your inquiries to the UFIRB office, P. O. Box 112250, University of Florida, Gainesville, FL 32611-2250; phone 392-0433.

If you wish to participate in this experiment, please sign and date a copy of this Informed Consent below and return it to the experimenter. This will indicate your voluntary willingness to participate. If you prefer not to participate, you may leave.

Similarity Question

The two problems you just worked were similar. In the space below, please explain in detail the features of the problems you believe were similar. In addition, if these similar features helped you to solve the second problem, please explain in detail how they did so.

Debriefing Statement

The experiment you participated in today was designed to explore the various difficulties encountered in understanding how to solve problems that require deductive reasoning. Deductive reasoning is a process through which you are given some specific information, such as the rule concerning which figures can be classified as THOGs and an example of a THOG, and you must then draw a logical conclusion (in other words, a conclusion concerning which of the other figures may or may not be THOGs) based on this information. Different participants received slightly different versions of this problem in order that we might gain a better understanding of how various components of the problem might help or hinder understanding of the required task. By determining which versions of the task are easier to solve, we hope to learn the underlying thinking and problem solving processes that are necessary for gaining a complete understanding of the problem's structure. Because this experiment is continuing throughout the semester, we ask that you not discuss the problem with your classmates. If you are interested in learning more about this experiment and how to solve this problem, a more complete debriefing will be held on *Date Inserted* in *Location Inserted* at *Time Inserted*. Thank you very much for your participation.

APPENDIX D
ERROR PATTERNS

D-1. Error patterns in Experiment 1

	Problem condition						
Error pattern	Standard		Blackboard		Pythagoras		
	Problem		Problem		Problem		
	Source	Target	Source	Target	Source	Target	Total
Intuitive A	6/22	5/21	2/11	4/13	1/6	5/12	23/85
Intuitive B	2/22	2/21	1/11	2/13	1/6	0/12	8/85
Near insight	1/22	1/21	0/11	0/13	0/6	1/12	3/85
All are THOGs	3/22	6/21	1/11	2/13	1/6	0/12	13/85
All are not THOGs	0/22	0/21	0/11	0/13	0/6	1/12	1/85
All can't tell	0/22	1/21	0/11	2/13	2/6	1/12	6/85
Total	12/22	15/21	4/11	10/13	5/6	8/12	54/85

D-2. Error patterns in Experiment 2

Error pattern	Problem condition						
	Standard Problem		Blackboard Problem		Pythagoras Problem		
	Source	Target	Source	Target	Source	Target	Total
Intuitive A	9/30	9/29	3/19	4/24	3/18	3/21	31/141
Intuitive B	2/30	3/29	4/19	5/24	1/18	4/21	19/141
Near insight	1/30	1/29	1/19	0/24	1/18	1/21	5/141
All are THOGs	6/30	5/29	2/19	2/24	0/18	1/21	16/141
All are not THOGs	1/30	2/29	0/19	1/24	0/18	2/21	6/141
All can't tell	3/30	2/29	1/19	2/24	4/18	2/21	14/141
Total	22/30	22/29	11/19	14/24	9/18	13/21	91/141

D-3. Error patterns in Experiment 3

Error pattern	Problem condition				
	Standard Problem		Pythagoras Problem		
	Source	Target	Source	Target	Total
Intuitive A	8/29	10/28	2/12	4/16	24/85
Intuitive B	4/29	5/28	1/12	4/16	14/85
Near insight	1/29	1/28	2/12	1/16	5/85
All are THOGs	4/29	3/28	1/12	1/16	9/85
All are not THOGs	1/29	3/28	0/12	0/16	4/85
All can't tell	2/29	0/28	2/12	5/16	9/85
Total	20/29	22/28	8/12	15/16	65/85

D-4. Error patterns in Experiment 4

	Problem condition								
Error pattern	Standard		Label + Narrative		Label + Hyp Gen		Narrative + Hyp Gen		
	Problem		Problem		Problem		Problem		
	Source	Target	Source	Target	Source	Target	Source	Target	Total
Intuitive A	8/25	4/22	2/19	4/16	3/14	2/11	4/16	5/13	32/136
Intuitive B	3/25	3/22	6/19	6/16	0/14	0/11	2/16	3/13	23/136
Near insight	1/25	2/22	1/19	1/16	0/14	1/11	1/16	1/13	8/136
All are THOGs	4/25	3/22	2/19	1/16	2/14	1/11	0/16	0/13	13/136
All are not THOGs	3/25	3/22	1/19	2/16	1/14	0/11	2/16	2/13	14/136
All can't tell	1/25	0/22	3/19	0/16	1/14	4/11	1/16	0/13	10/136
Total	20/25	15/22	15/19	14/16	7/14	8/11	10/16	11/13	100/136

BIOGRAPHICAL SKETCH

Cynthia Summers Koenig received her Bachelor of Science, summa cum laude, from Kennesaw State University on December 11, 1993. Her major degree of study was psychology and her minor degree of study was women's studies. She enrolled in the graduate program in developmental psychology at the University of Florida in August 1994. While working on her master's thesis, she was supported by a NICHD Pre-Doctoral Traineeship Grant. She received her master's degree and a gerontology certificate from the University of Florida in May 1999. She transferred to the cognitive/sensory psychology area at the University of Florida in June 1999.

During her graduate career at the University of Florida, Cynthia received a VanderWerf Graduate Student Teaching Award, the Pioneer Award for excellence in academic performance and promise in conducting research in the science of psychology, and the Porter Horne Memorial Award for outstanding performance in the cognitive/sensory area of psychology. She was also awarded a Gerson Dissertation Fellowship from the College of Liberal Arts and Sciences.

Cynthia is currently a student member of the Teaching of Psychology division of the American Psychological Association, a student affiliate of the American Psychological Society, and a graduate member of the Southeastern Psychological Association. After receiving the Doctor of Philosophy degree in August 2002, she will begin an Assistant Professor of Psychology position at St. Mary's College of Maryland.

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

Richard A. Griggs, Chairman
Professor of Psychology

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

Ira S. Fischler
Professor of Psychology

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

Shari Ellis
Assistant Professor of Psychology

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

M. Jeffrey Farrar
Associate Professor of Psychology

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

James Algina

James Algina
Professor of Educational Psychology

This dissertation was submitted to the Graduate Faculty of the Department of Psychology in the College of Liberal Arts and Sciences and to the Graduate School and was accepted as partial fulfillment for the degree of Doctor of Philosophy.

August 2002

Dean, Graduate School